1. AGENCY USE ONLY (Leave blank)	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	3-22-94	Final-Phase I, 6-1-93 to 2-28-94

4. TITLE AND SUBTITLE

Materials for Spectral Hole Burning Research

5. FUNDING NUMBERS

C-F49620-93-C-0023

6. AUTHOR(S)

R.L. Hutcheson R. Cone

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

Scientific Materials Corporation
310 Icepond Road
Bozeman, MT 59715

8. PERFORMING ORGANIZATION REPORT NUMBER

SM-94-0006

AFOSR-TR- 94 0233

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

Air Force Office of Scientific Research
110 Duncan Ave. B 115
Boling AF Base, DC 20332-0001

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

3005/SS

11. SUPPLEMENTARY NOTES

58 Pg

426003

12a. DISTRIBUTION/AVAILABILITY STATEMENT

Subject to SBIR Data Rights, Limitations
No DOD or U.S. Gov't Restrictions

Approved for public release;
distribution unlimited.

13. ABSTRACT *(Maximum 200 words)*

Work on the crystal growth and evaluation of crystals for PSHB application has shown good high quality crystals of yttrium silicate, calcium tungstate, and yttria are feasible. Dopants discussed are praseodymium, samarium and europium. The work shows Sm:two plus is not feasible in calcium tungstate. A sample of Eu:yttrium silicate shows one half homogeneous linewidth of previous Eu:yttrium silicate.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Holeburning crystal growth, yttrium silicate, calcium tungstate, yttria	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

Contractor Report - SM94-0006

MATERIAL FOR SPECTRAL HOLE BURNING RESEARCH

Reported by: Ralph L. Hutcheson
Principal Investigator

Scientific Materials Corporation
Bozeman, Montana

Contract No. F49620-93-C-0023
March 22, 1994

Table of Contents

SUMMARY:

There is a need to support research in spectral hole burning with a complimentary materials research program. The Phase I program was to show the feasibility of such a program and to demonstrate the capabilities of the crystal grower to provide dopants in multiple hosts.

In the work on this program, Scientific Materials Corporation grew crystals of the following compositions.

Dopant	Growth Method
1.0% Tm:YAG	Czochralski
0.1% Tm:YAG	Czochralski
0.1% Sm:$CaWO_4$*	Czochralski
0.1% Pr:$CaWO_4$*	Czochralski
0.1% Eu:Y_2O_3*	Flame Fusion
0.1% Eu:Y_2SiO_5*	Czochralski
0.1% Tm:Y_2SiO_5	Czochralski

The crystals were fabricated and provided to Dr. R. Cone at Montana State University for characterization. Results on the * crystals are presented. Other materials are waiting evaluation.

One unique result was a sample of Eu:Y_2SiO_5 showed a lower homogeneous linewidth than any other reported sample. Other crystal evaluation results were similar to previous data. The samarium in $CaWO_4$ was determined to be three plus with no evidence of any two plus ions in the crystal. This was not an expected result.

Montana State University has developed a bibliography on materials for spectra hole burning, however for copyright reasons the list can not be presented as yet. In addition, a list of all elements and isotopes have been prepared showing the ionic radii and magnetic moments properties critical to this application.

(2) Private Communications with E. Zharikov, USSR Academy of Science, Feb. 1994.

INTRODUCTION:

The work to be performed under this contract is comprehensively stated in the Statement of Work.

"Scientific Materials Corporation (SM) shall demonstrate its capability in growing rare earth doped oxides by delivering crystals grown by the Czochralski method of the following compositions: 0.1% doped Eu:Y_2SiO_5, 0.1% doped Pr:$YAlO_3$ and 0.1% doped Sm:$CaWO_4$. These crystals should be approximately 25mm in diameter and 100mm in length. These crystals shall be fabricated into samples for characterization. The contractor shall characterize them for dopant concentration, absorbance spectra, and optical quality. Their consultant, Dr. Cone, shall measure material structure and absorptive linewidth, as well as other properties pertinent to persistent spectral hole burning (PSHB) applications. Other similar materials that may hold greater promise for PSHB may be substituted with the consent of the Contracting Officer.

Scientific Materials Corporation shall employ a consultant (Dr. Cone) and a graduate student under his direction to catalog all known rare earth -- host crystal combinations that evidence PSHB attributes. This ancillary effort is pursuant to follow-on (Phase II) plans to establish a crystal growth modeling capability that would reduce the number of multiple Edisonian experiments and costly analyses generally required to determine composition and growth process for a new material and its application."

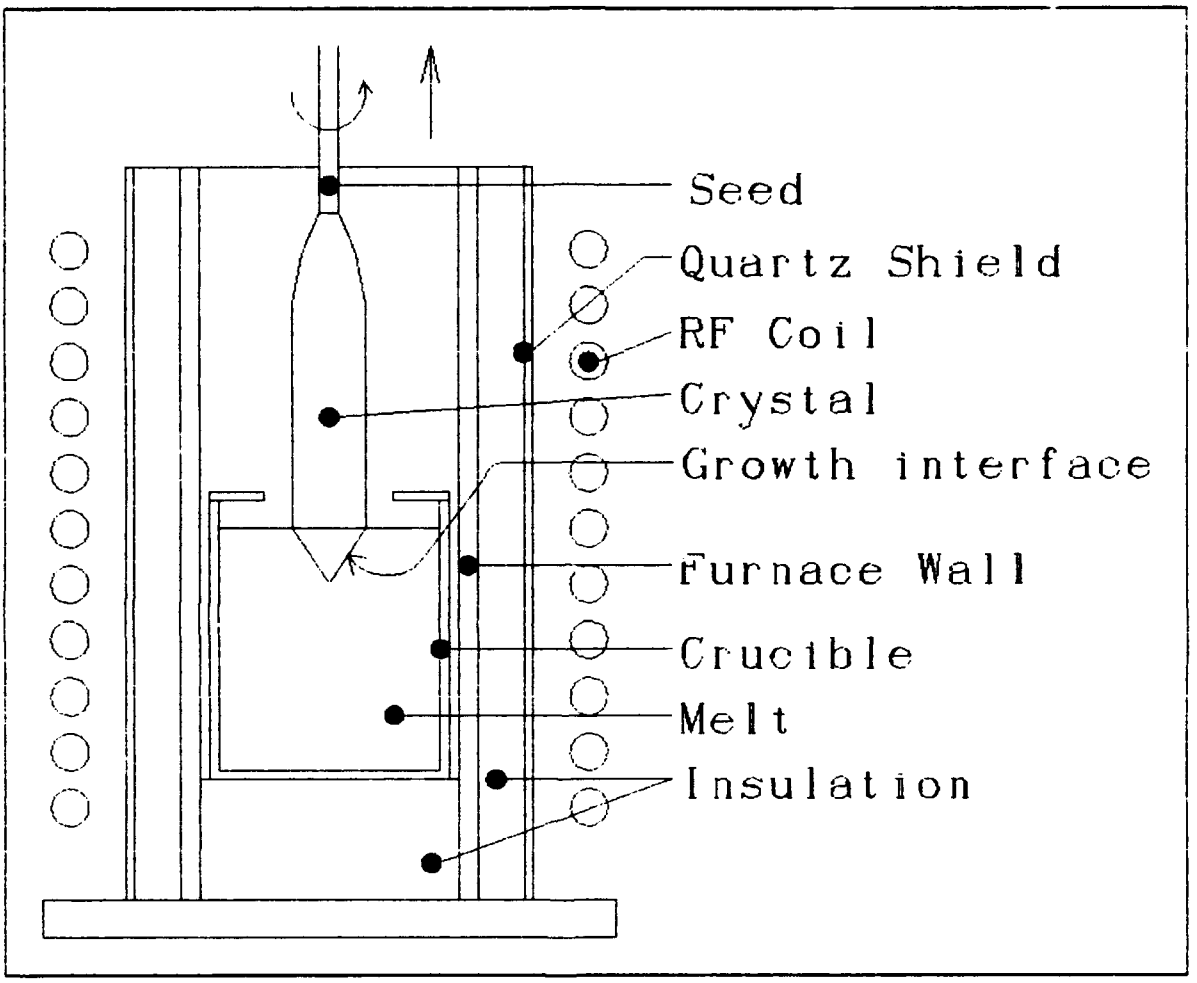
The technical community associated with this program had no technical interest in Pr:$YAlO_3$ and asked to substitute Pr:$CaWO_4$ and Eu:Y_2O_3 which was done. It was also requested SM supply Tm:YAG which was done on approval of the Program Manager.

METHODS, ASSUMPTIONS AND PROCEDURES:

Scientific Materials Corporation employs two methods of crystal growth. The Czochralski (CZ) method is a melt process which uses an iridium crucible to hold the melt from which a crystal is pulled, normally on a seed crystal. This process is shown schematically in Figure 1.

Figure 1

Czochralski (CZ) Crystal Setup



The Verneuil or flame fusion (FF) process uses a flame to melt the cap of a seed crystal and then powder is passed through the flame and deposited on that molten cap. This process is shown schematically in Figure 2.

At SM, CZ is used for materials which have a melting point less than 2100°C. FF is used for materials with a melting point up to 2500°C. Crystals grown by FF are normally small and of poor quality. However, samples are adequate for properties measurements which is a primary purpose of this program.

Crystals grown by CZ are normally of high quality and substantially larger in size than FF. CZ also provides better atmosphere control essential to the growth of many complex crystals.

RESULTS AND DISCUSSION:

Table One summaries the crystal growth runs. As can be observed, most of the crystal growth work was devoted to Yttrium Silicate (YSO). It is the normal practice of SM to obtain the highest purity raw material economically available, purify the materials by recrystallization and then grow the final product. In the case of YSO, this was not possible. Our source of SiO_2 was electronic grade quartz. The source of Y_2O_3 was inventoried material, approximately 6-9's pure. The concept was to melt the SiO_2 and dissolve the Y_2O_3 into the SiO_2.

After destroying two crucibles and four crystal growth furnaces, it was ascertained this concept does not work. The problem is twofold. First, the SiO_2 apparently forms a gas phase as the temperature increases above the melting point and this gas phase attacks the boundaries of the iridium causing pin hole leaks. As the crucible then heats up, the liquid flows through the pin holes forming a eutectic with the zirconia furnace causing the furnace to melt. This problem occurs occassionally in the growth of other crystals.

Figure 2
Verneuil (Flame Fusion)

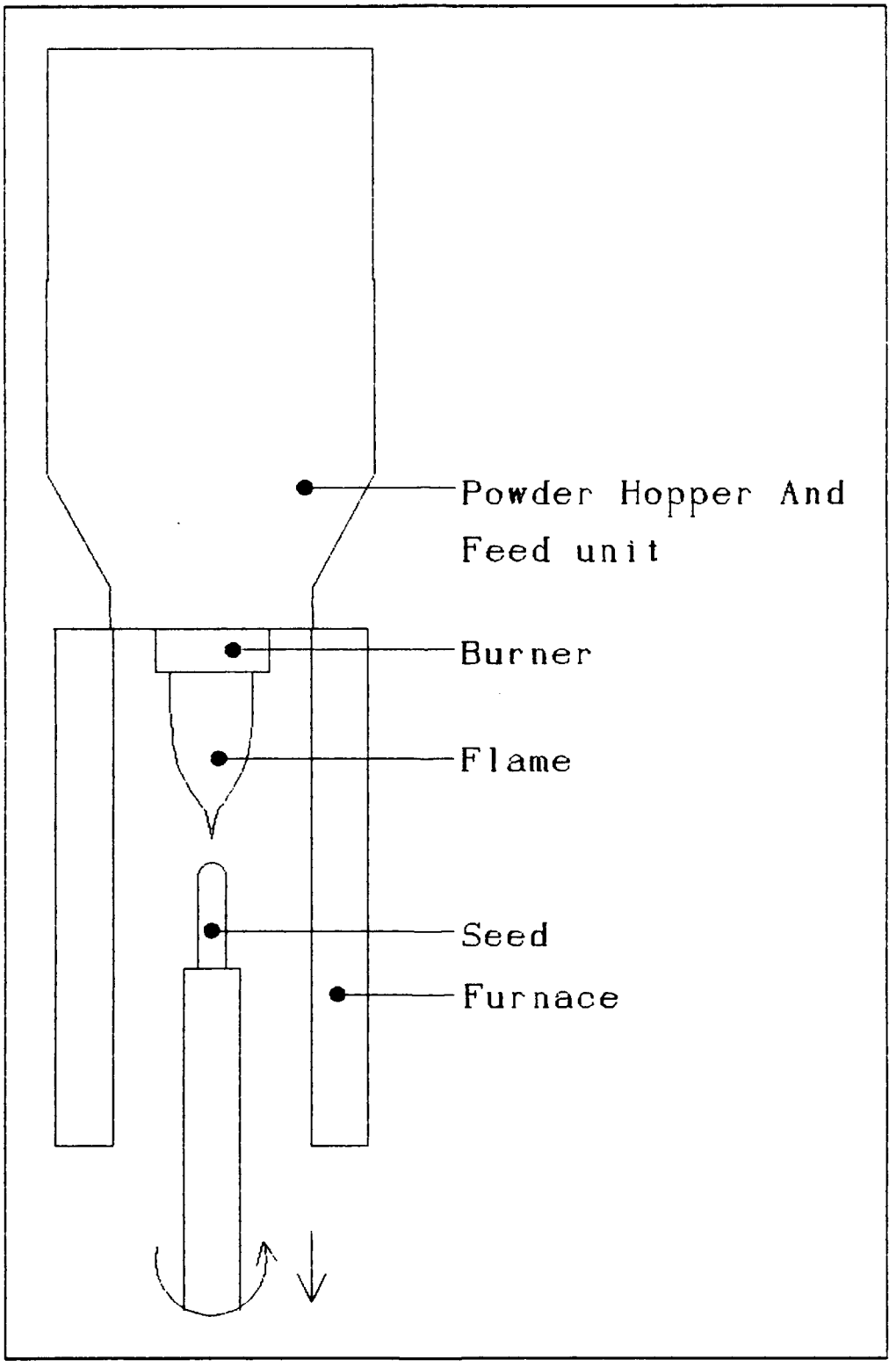


TABLE ONE

RUN #	MATERIAL	RESULTS
CZOCHRALSKI METHOD		
5-231	YSO	Achieved melt, no control
5-232	YSO	Achieved melt, no control
5-233	YSO	Melted crucible
5-234	Cleaning run	
5-235	Cleaning run	
5-236	Y_2O_3, FF furnace sintering run	
5-237	YSO	Melted furnace
5-238	YSO	Loading problem
5-239	Crucible annealing	
5-240	Yb:YAG	Station test
5-241	YSO	Melt formed, seed broke
5-242	Crucible annealing	
5-243	Crucible annealing	
5-244	Crucible cleaning	
5-245	Crucible cleaning	
5-246	Crucible cleaning	
5-247	Crucible cleaning	
5-248	Sm:$CaWO_4$	
5-249	Sm:$CaWO_4$	167.5 gm crystal, 30mm x 50mm
5-250	Pr,Sm:$CaWO_4$	152.5 gm crystal, 27mm x 50mm
5-251	Cleaning run	
5-252	Cleaning run	
5-253	Cleaning run	
5-254	Eu:YSO	Loading problem
5-255	Eu:YSO	Seed broke
5-256	Eu:YSO	Seed broke
5-257	Eu:YSO	Anode blew, Geode formed
5-258	Eu:YSO	Crucible zippered
5-259	Eu:YSO	Seed broke
5-260	Eu:YSO	Seed melted
5-261	Eu:YSO	Material crystallized off IR rod Good crystals
5-262	Eu:YSO	Material crystallized off IR rod Good crystals

TABLE ONE (continued)

RUN #	MATERIAL	RESULTS
FLAME FUSION METHOD		
S-2-251	Eu:Y_2O_3	4cm length crystal - cloudy
S-2-252	Eu:Y_2O_3	Powder feed problem
S-2-253	Eu:Y_2O_3	2cm length crystal, one small clear section
S-2-254	Eu:Y_2O_3	Burner plugged, H_2 failure

In addition, in the case of SiO_2 there is a very large differential between the coefficient of thermal expansion of quartz and iridium, with iridium being much higher. Since the liquid is predominately fused quartz at the time of shutdown, a slug of solid quartz is formed at the bottom of the crucible. Since the iridium can not contract, as soon as it reaches the brittle state the material develops stress cracks which are extremely difficult to repair.

On realizing the SiO_2/iridium problem, the melt loading was switched to a yttria rich composition. Six 9's pure SiO_2 was obtained from ProChem, Inc. This material was mixed with Y_2O_3 in two compositions, 12% SiO_2 and 24% SiO_2. (wt.%) The 12% material is an eutectic composition. By first melting this material and dissolving the higher concentration into the melt, no free SiO_2 is exposed to the iridium. Using this method, near stoichiometry melts could be established and maintained.

However, the next discovery was YSO does not like YAG or sapphire, the normal materials of construction for seed holders. Per discussions with Dr. Bruce Chai, University of Central Florida, it is believed the problem is caused by SiO_2 vapor over the melt forming mullite (Al_2SiO_5) on the surface of the YAG and sapphire causing cracking to occur. This is highly speculative but the results show every piece of sapphire or YAG suspended over the melt cracked or shattered.

The seed problem was reduced to something workable by using an iridium rod. Some reasonable size crystals have been produced using an iridium starter rod.

A common technique used among crystal growers to establish a seed is to establish a melt and then slowly cool that melt to allow natural nucleation to establish fairly large seed crystals. This does not happen with YSO. Rather in all cases except Run 5-257, the solidified melt was a polycrystalline mass. In Run 5-257, the melt cooled equally from the top and bottom leaving a hollow in the center, exactly like a geode. The walls of this hollow were lined with numerous small crystals, some large enough to measure

absorption. The results are reported under Dr. Cone's section. The results of run 5-260 and 5-261 will be reported later as the material has only recently been made available to Dr. Cone.

The flame fusion growth of Y_2O_3 resulted in two small crystals. The internal quality was poor, in part owing to growing the crystal blind. In normal FF growth, the powder feed rate is controlled by observing the crystal growth interface through a site hole. In all cases where Y_2O_3 was grown in view, the crystal showed extensive cleavage. In attempts to increase diameter, the crystal was allowed to grow up into the furnace. The diameter did increase but only about 20%, however the crystal did not cleave. Since control of the growth under blind conditions was beyond the scope of the Phase I program, work was discontinued. Samples were fabricated sufficiently clear for Dr. Cone to make measurements.

The other host crystal evaluated for Phase I was $CaWO_4$. The crystal was originally grown by CZ in the early 1960's and sold as a commercial laser. The host was selected as a potential $^{2+}$ site for Sm. The technical group felt $CaWO_4$ would also be a host for Pr^{3+}. Attempts to grow $CaWO_4$ in a neutral atmosphere did not work as the compound is highly unstable. The material essentially sublimes, first depositing a white coating on everything, followed by a black coating. The second material is probably WO_6.

By growing the crystal in air, the vaporization is reduced allowing the growth of a fairly good crystal. Crystals containing Sm and Sm:Pr were grown. Evaluation by Dr. Cone showed all the Sm in the crystal was $^{3+}$. There was no evidence of any $^{2+}$ which was a surprise. Re-evaluating the concept uncovered two things which are believed to be the reasons for this. First, the site is small for Sm^{2+} but the ionic radius is within the allowable limits for substitution. Second, is that Shannon in his work on ionic radius determination[1], showed no octahedral form for Sm^{2+} and in octahedral configuration Sm favors the $^{3+}$ ionic state. Since the Ca site in $CaWO_4$ is octahedral, this would indicate Sm will substitute only as a $^{3+}$ ion in $CaWO_4$.

[1] See Appendix D

The following are the analytical results on the crystals tested to date.

Y_2O_3 & Y_2SiO_5	Appendix A
$CaWO_4$	Appendix B

Results of the literature survey and material data catalog follow.

Literature Survey	Appendix C
Table of Ionic Radii	Appendix D
Table of Isotopes of Elements and other magnetic moments	Appendix E
Table of Isotopes of the Element which are naturally occurring and their magnetic moments	Appendix F
Table of natural occurring isotope of elements with nuclear spin of zero and their magnet moments	Appendix G

CONCLUSIONS:

The work on Phase I has demonstrated the feasibility of making improved crystals for PSHB technology development. For example, tests on the small Eu:YSO crystal showed homogeneous linewidth, 1/2 those of R. MacFarlanes' Japanese crystal.

It is felt enough understanding of materials related to PSHB has been developed to engineer crystals more ideal for the application. The work on Sm in $CaWO_4$ was particularly meaningful in that it shows clearly arbitrary selection of dopant host combinations is not the way to go. It is with this purpose in mind that the tables in Appendices D,E,F, & G were produced.

Based on the work reported here and work at other laboratories in the U.S. and Russia, YSO is not a fully understood material. The Russians believe the material is two phase and say they have evidence of Si_2O_7[2]. In residual melts at SM, evidence of color centers is observed indicating this may be true. Also in growth at both the University of Central Florida and SM an unusually high melt tosolid volume ratio is observed. It is concluded from these observations, the published phase diagram is suspect and a better understanding of the crystallization is necessary.

Absorption and Photon Echo Measurements on $Eu^{3+}:Y_2O_3$ and $Eu^{3+}:Y_2SiO_5$ Crystals

by
Randy Equall, Calvin Harrington, and Rufus Cone
Physics Department, Montana State University

for Scientific Materials Corporation
February, 1994

The spectroscopic properties of $Eu^{3+}:Y_2O_3$ and $Eu^{3+}:Y_2SiO_5$ single crystals prepared by Scientific Materials were investigated at MSU at liquid helium temperature (1.3 K). The primary goals were to determine the presence of Eu^{3+}, to determine the Eu^{3+} absorption coefficients α for the important $^7F_0$ to $^5D_0$ transition, and to measure the optical dephasing times T_2 and fluorescence lifetimes T_1 for the $^7F_0$ to $^5D_0$ transitions and compare the results to those for crystals from other sources.

The primary features in the visible absorption spectra of both samples were identified as Eu^{3+} lines corresponding to transitions from the ground state $^7F_0$ to excited states $^5D_0$, $^5D_1$, $^5D_2$, and $^5D_3$. Each crystal has two normal sites; absorption was observed for both sites in $Eu^{3+}:Y_2SiO_5$, as expected from earlier studies, but absorption was observed for only one of the sites in $Eu^{3+}:Y_2O_3$, again as expected -- the other site has inversion symmetry.

Photon echoes, time-resolved fluorescence, and laser absorption spectra (to obtain accurate line widths and absorption coefficients) were observed for the allowed $^7F_0$ to $^5D_0$ transitions and are summarized below.

$Eu^{3+}:Y_2O_3$

1.5 mm thick unoriented sample gave 23 % absorption

absorption coefficient	$\alpha = 1.4\ cm^{-1}$
transition wavelength	$\lambda = 580.72$ nm in air
fluorescent lifetime	$T_1 = 880\ \mu sec$
optical dephasing time	$T_2 = 40\ \mu sec$
homogeneous optical line width	$\Gamma_h = 8$ kHz
inhomogeneous absorption line width	2.8 GHz (fwhm)

The echo decay time is about 10x faster than for the best known crystal and is comparable to values derived from samples prepared by laser-assisted pedestal growth.

$Eu^{3+}:Y_2SiO_5$ site 1

2.24 mm thick unoriented sample gave 20 % absorption

absorption coefficient	$\alpha = 1.0\ cm^{-1}$
transition wavelength	$\lambda = 579.88$ nm in air
fluorescent lifetime	$T_1 = 1.9$ msec
optical dephasing time	$T_2 = 990\ \mu sec$ (unshielded sample - value comparable to IBM sample from Japan)
homogeneous optical line width	$\Gamma_h = 321$ Hz
inhomogeneous absorption line width	1.8 GHz (fwhm) [3.6 GHz for IBM sample]

$Eu^{3+}:Y_2SiO_5$ site 2

2.24 mm thick unoriented sample gave 18 % absorption

absorption coefficient	$\alpha = 0.9\ cm^{-1}$
transition wavelength	$\lambda = 580.05$ nm in air
fluorescent lifetime	$T_1 = 1.7$ msec
inhomogeneous absorption line width	1.3 GHz (fwhm) [3.3 GHz for IBM sample]

(echoes were not measured for site 2 since site 1 gave results comparable to other samples)

Eu concentration in the Y_2SiO_5 sample

We cannot estimate the concentration with a reasonable uncertainty by comparing the absorption coefficients observed for this sample with the values obtained for the IBM crystal. Absorption coefficients are direction- and polarization-dependent, so precise comparisons cannot be made until the crystals are oriented. The potential uncertainties are too large for even a ballpark estimate.

The observed inhomogeneous absorption coefficients are listed below for

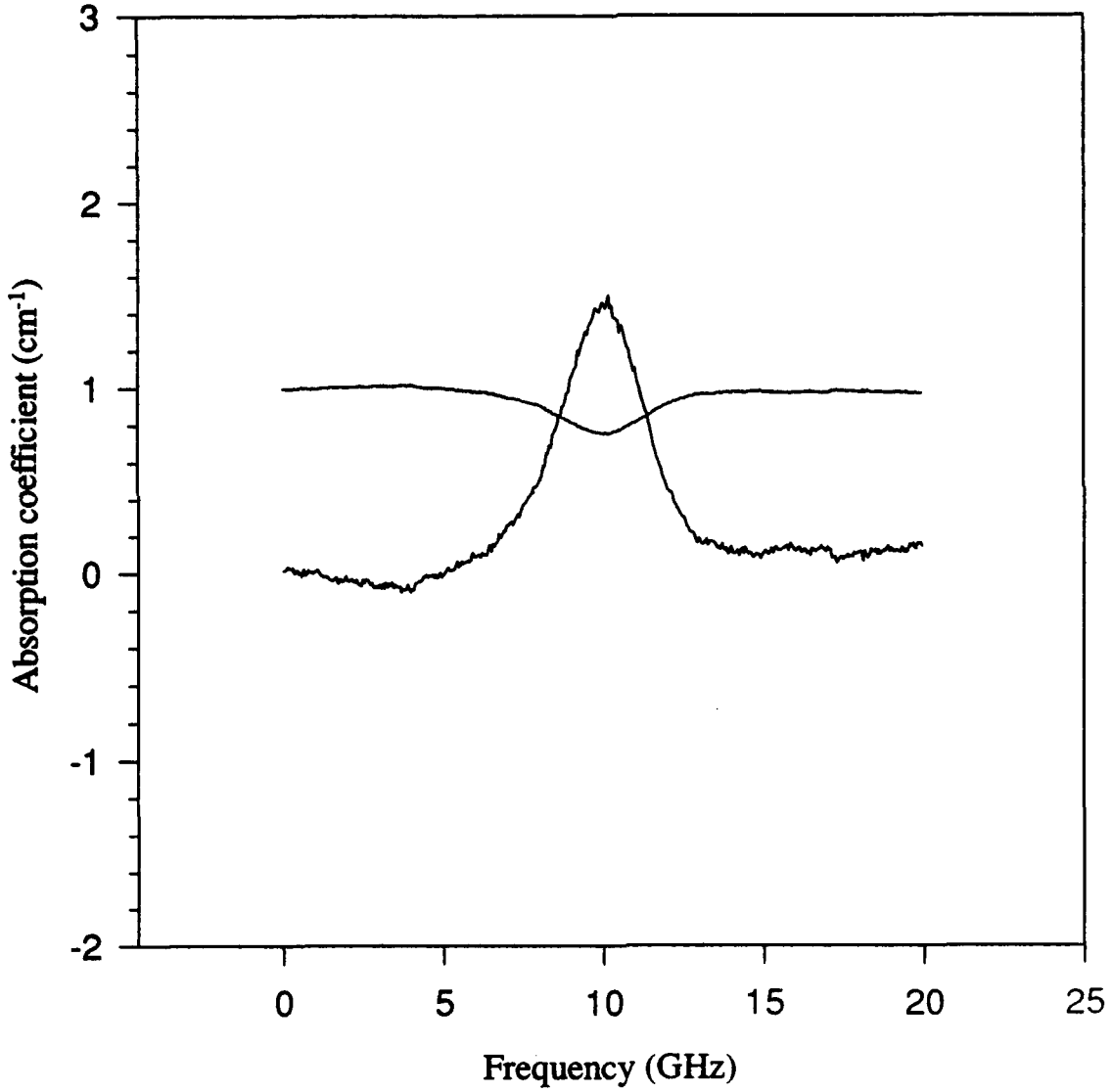
	Scientific Materials sample	0.1 % IBM sample (Japan)
site 1	$\alpha = 1.0\ cm^{-1}$	$\alpha = 0.5\ cm^{-1}$
site 2	$\alpha = 0.9\ cm^{-1}$	$\alpha = 1.4\ cm^{-1}$

Remark on Y_2SiO_5 sample quality

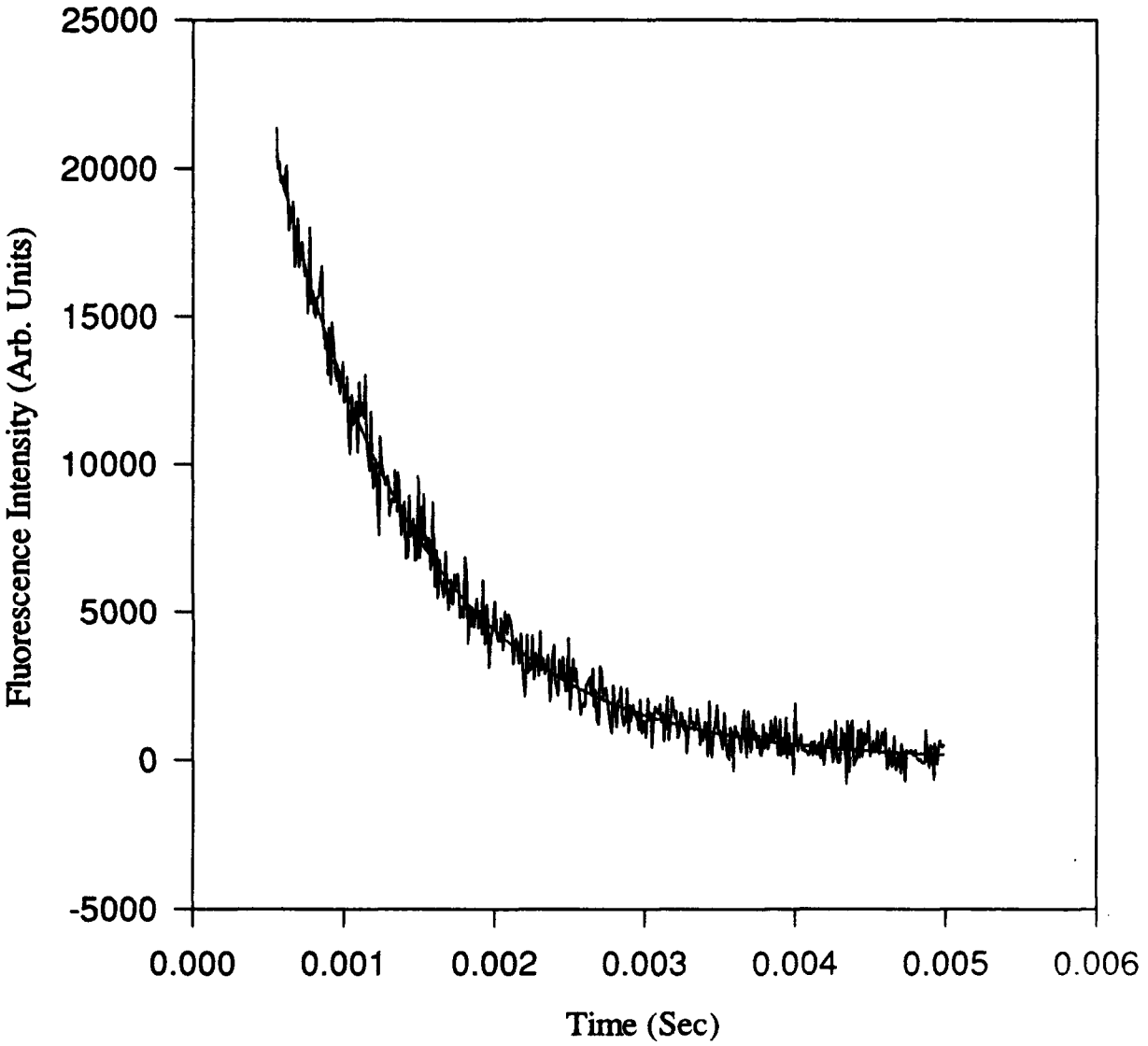
The inhomogeneous absorption linewidths for the YSO crystal are less than half as large as for the IBM sample from Japan. Generally, this is a function either of Eu^{3+} concentration or of "crystal perfection."

Attached are copies of the absorption and fluorescence spectra.

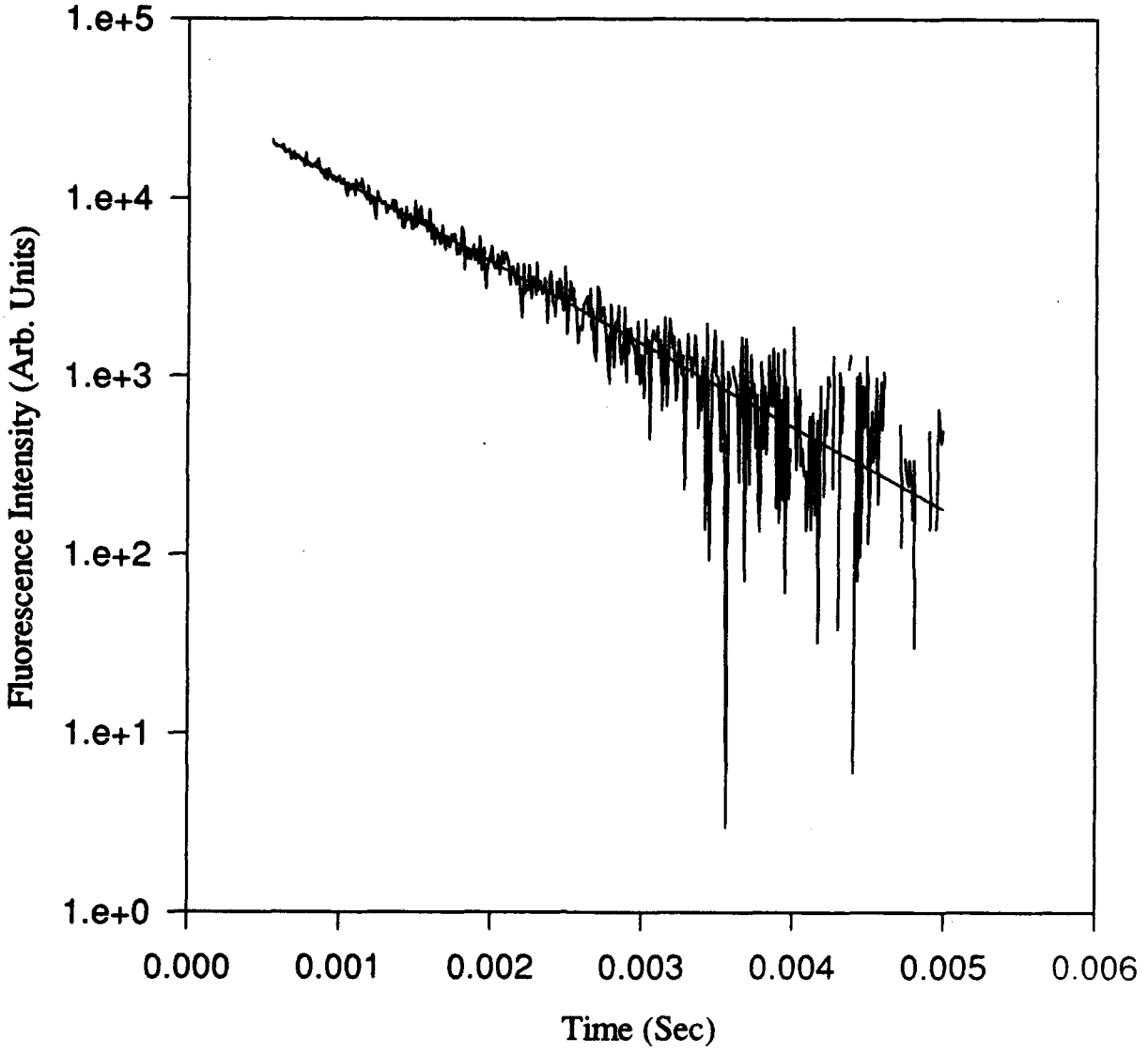
$Eu^{3+}:Y_2O_3$


3
2
1
0
-1
-2
Absorption coefficient (cm-1)
0
5
10
15
20
25
Frequency (GHz)

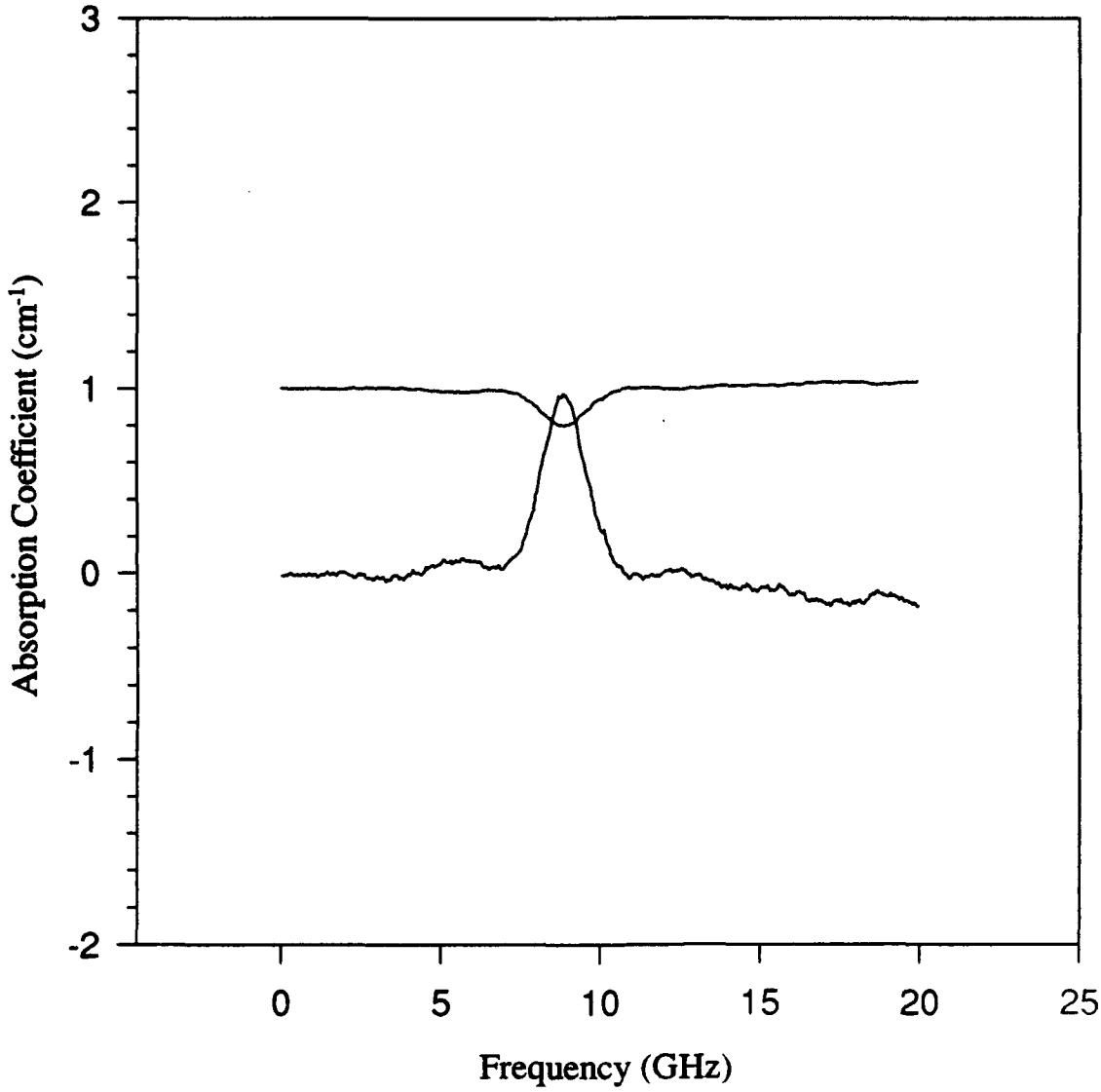
$Eu^{3+}:Y_2O_3$


25000
20000
15000
10000
5000
0
-5000
Fluorescence Intensity (Arb. Units)
0.000
0.001
0.002
0.003
0.004
0.005
0.006
Time (Sec)

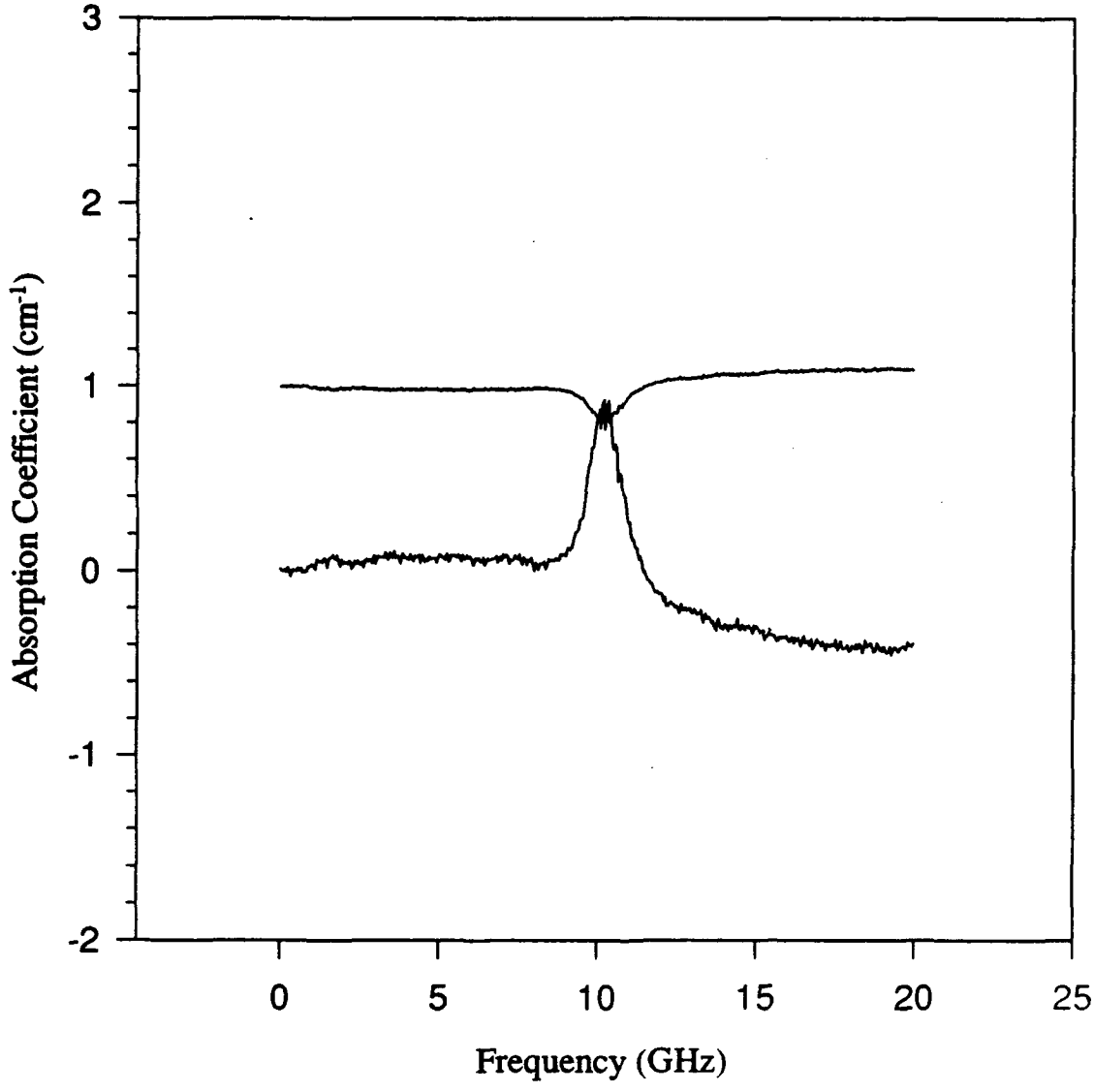
$Eu^{3+}:Y_2O_3$


1.e+5
1.e+4
1.e+3
1.e+2
1.e+1
1.e+0
Fluorescence Intensity (Arb. Units)
0.000
0.001
0.002
0.003
0.004
0.005
0.006
Time (Sec)

$Eu^{3+}:Y_2SiO_5$
Site 1 @ 579.88nm

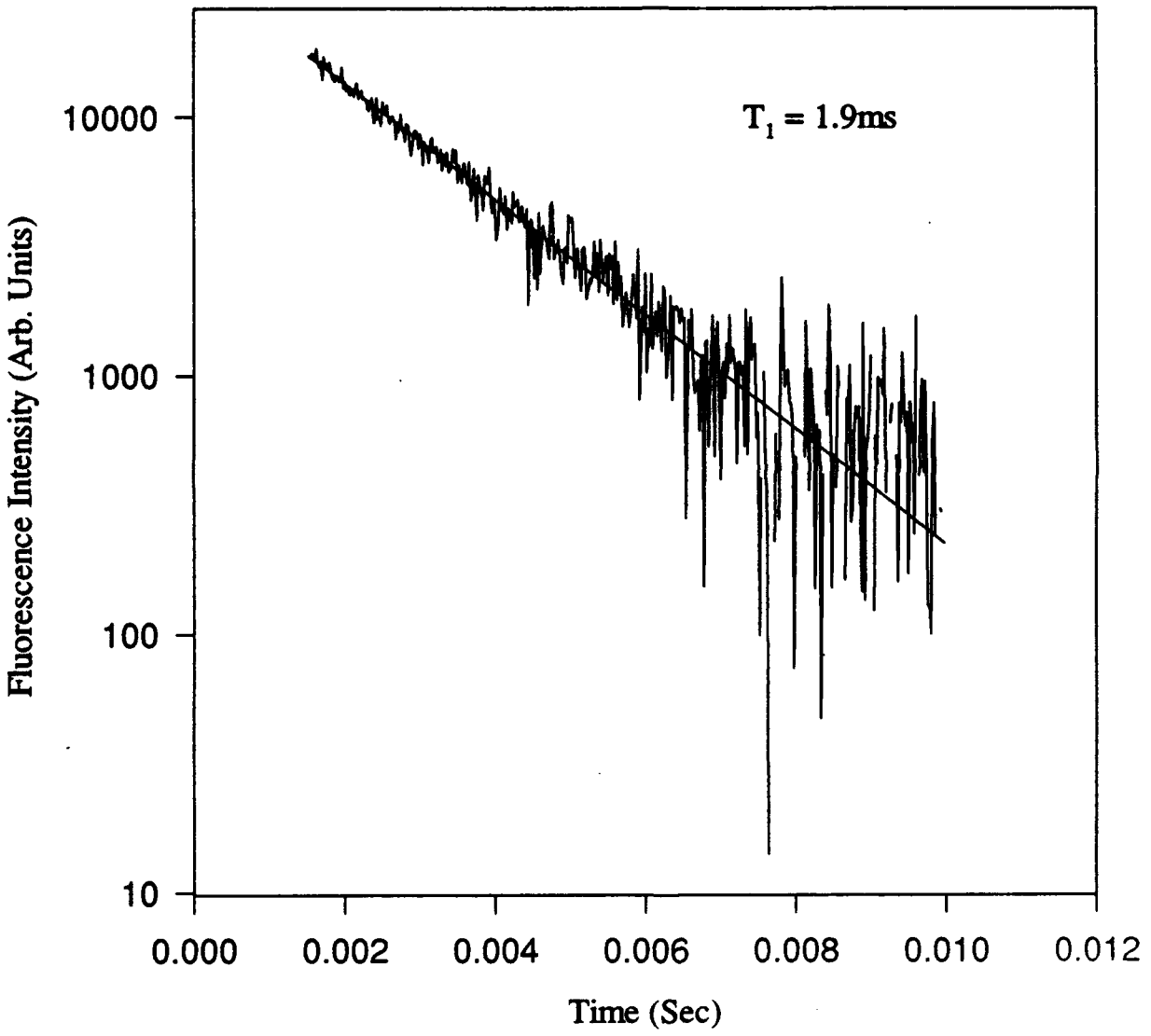


$Eu^{3+}:Y_2SiO_5$
Site 2 @ 580.05nm



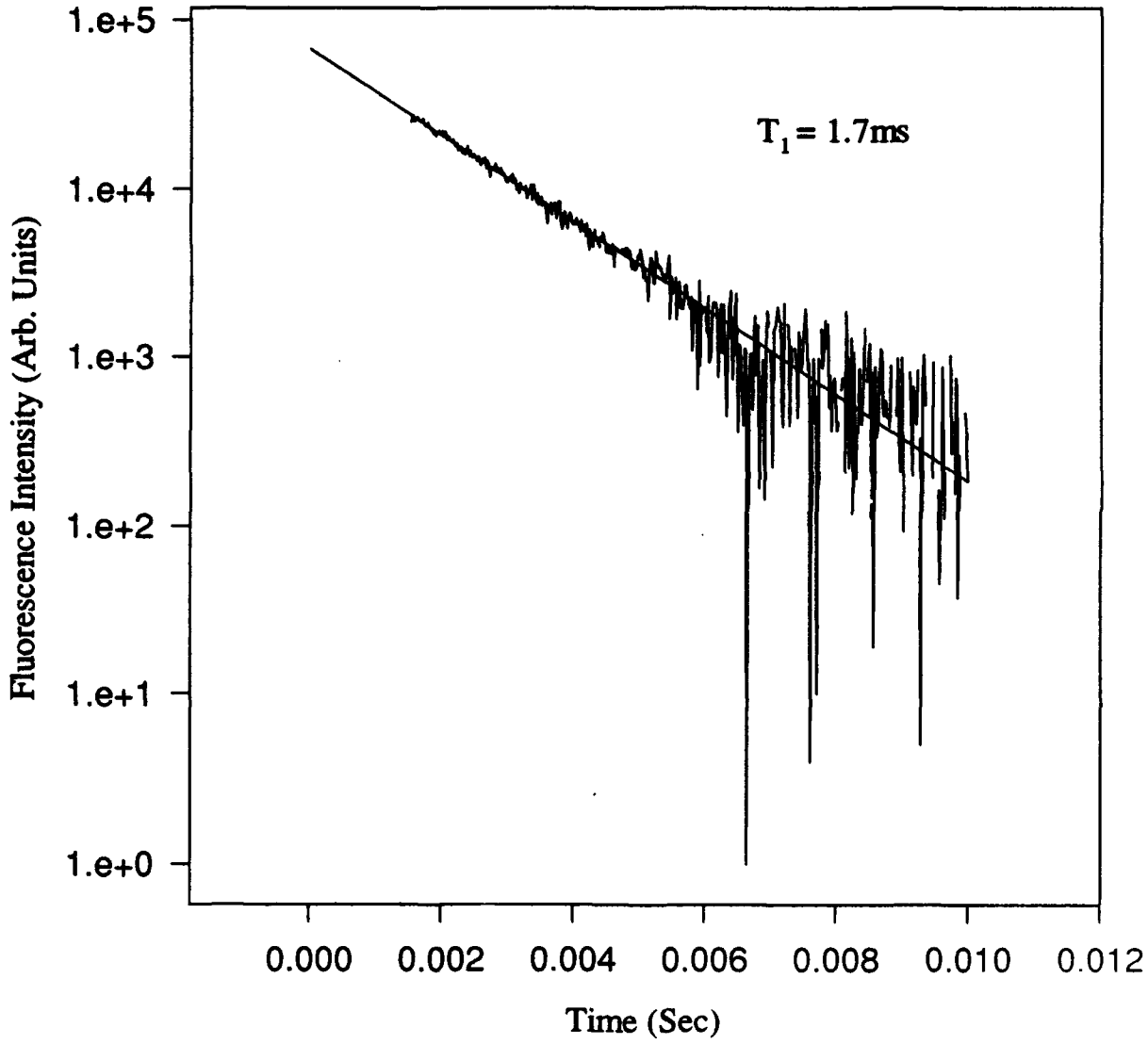
$Eu^{3+}:Y_2SiO_5$

Site 1 @ 579.88nm



$Eu^{3+}:Y_2SiO_5$

Site 2 @ 580.05nm



Absorption and fluorescence measurements on $CaWO_4$ crystals

by
Guangming Wang, Calvin Harrington, and Rufus Cone
Physics Department, Montana State University

for Scientific Materials Corporation
January, 1994

The spectroscopic properties of Sm:$CaWO_4$ and Pr:$CaWO_4$ prepared by Scientific Materials were investigated at MSU by absorption and fluorescence experiments at liquid helium temperature. One group of $CaWO_4$ samples was singly-doped with 0.1% Sm, and a second group was co-doped with 0.1% Sm and 0.1% Pr. In addition to obtaining Sm^{3+} and Pr^{3+} spectra, a major goal was to search for evidence of Sm^{2+} in any of the samples.

The primary features in the visible absorption spectra of 0.1% Sm:$CaWO_4$ were identified as Sm^{3+} lines corresponding to transitions from the ground state $^6H_{5/2}$ to the upper states $^4G_{5/2}$, $^6F_{3/2}$, $^4G_{7/2}$, $^4I_{9/2}$, $^4M_{15/2}$, $^4I_{11/2}$, $^4I_{13/2}$, and $^4F_{5/2}$. There were also several absorption lines at 17424.3 cm^{-1}, 17415.2 cm^{-1}, 17104.0 cm^{-1}, 17081.1 cm^{-1}, and 17039.6 cm^{-1} that could not be assigned to Sm^{3+}; we believe that they come from an impurity such as Nd^{3+}.

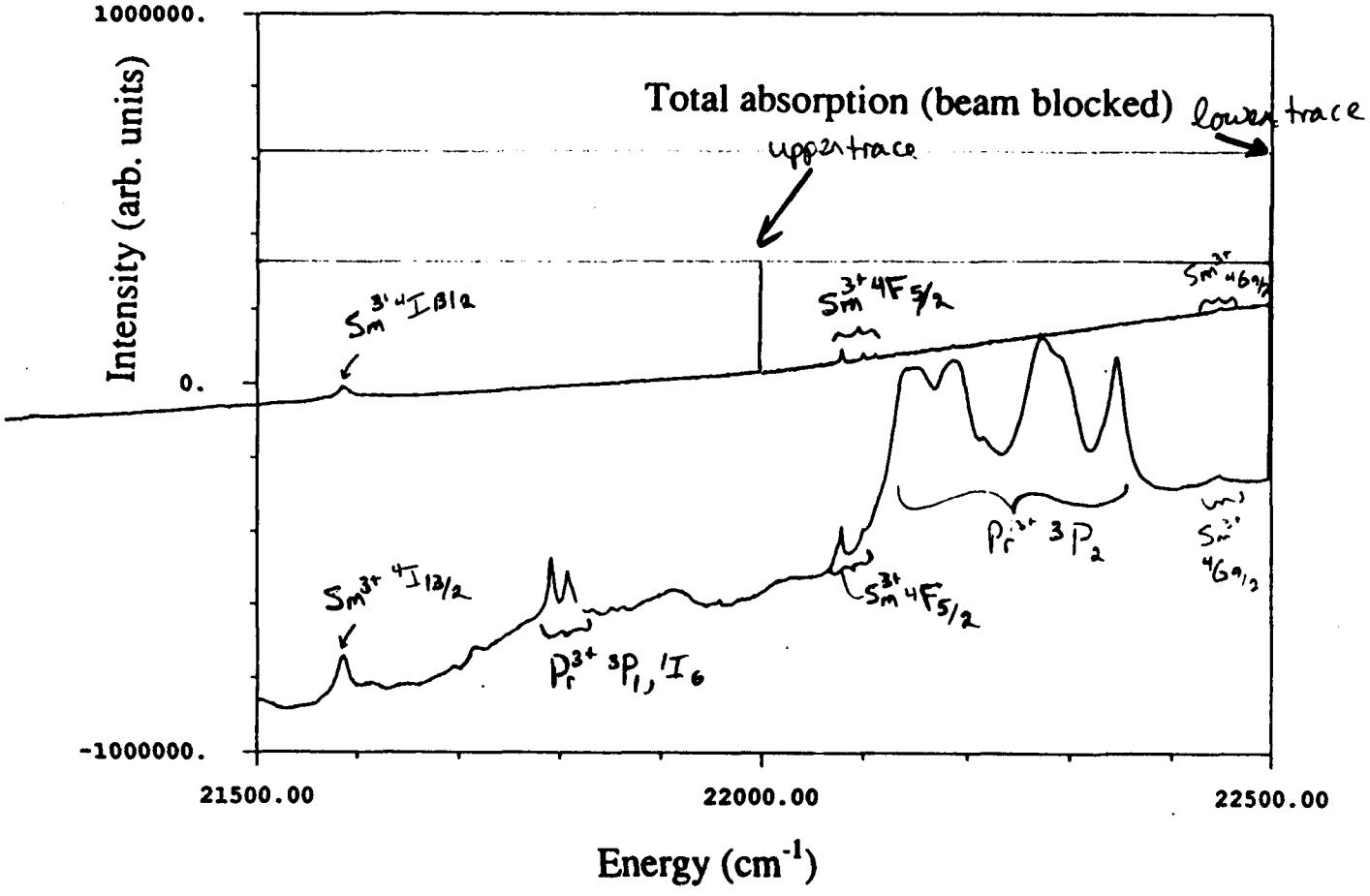
To demonstrate the presence of multiple Sm^{3+} sites resulting from varied charge compensation at the Ca^{2+} substitution sites, we excited the Sm^{3+} $^4G_{5/2}$ absorption lines at 17761.1 cm^{-1} and 17748.7 cm^{-1} with a pulsed tunable dye laser and observed fluorescence to the $^6H_{11/2}$, $^6H_{9/2}$, $^6H_{7/2}$, and $^6H_{5/2}$ states. The time-resolved fluorescence spectra arising from each type of excitation were similar, but differences between them indicate that the two absorption lines are due to Sm^{3+} ions in different sites. This is consistent with previous reports of $CaWO_4$ spectroscopy involving a variety of rare earth ions. We also excited the sample with the laser at the unidentified absorption lines at 17424.3 cm^{-1}, 17415.2 cm^{-1}, 17104.0 cm^{-1}, 17081.1 cm^{-1}, and 17039.6 cm^{-1}, but that yielded no visible fluorescence. Infrared fluorescence is expected if these lines belong to Nd^{3+} impurities, but we were not able to look for that with presently available detectors.

Absorption spectra of $CaWO_4$ co-doped with 0.1% Sm and 0.1% Pr were also measured. Those samples showed absorption due to the $^1D_2$, $^3P_0$, $^3P_1$, $^1I_6$, and $^3P_2$ energy levels of Pr^{3+} and also showed the same Sm^{3+} spectra described above. There were more Pr^{3+} lines than expected in each region, and we consider those "extra" lines to arise from multiple Pr^{3+} sites resulting from varied charge compensation.

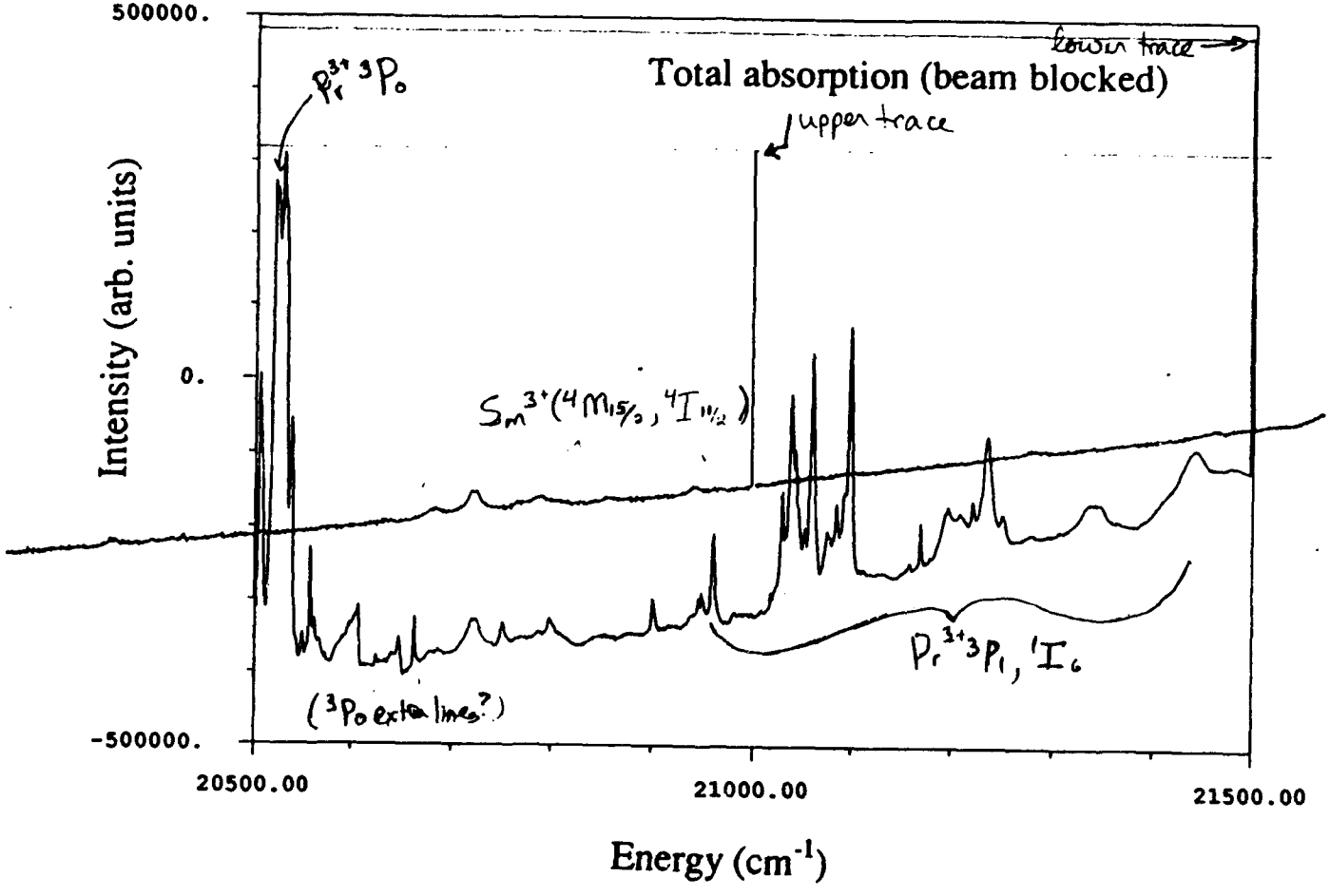
We searched for Sm^{2+} ions in the $CaWO_4$ samples by searching for sharp Sm^{2+} $4f^6$ absorption lines near 14532 cm^{-1} ($^5D_0$), 15870 cm^{-1} ($^5D_1$), and 17810 cm^{-1} ($^5D_2$) and for $4f^55d$ bands at energies up to 31,000 cm^{-1} (normally quite strong). After carefully examining those regions, we found no evidence of Sm^{2+}.

Attached are examples of the absorption and fluorescence spectra.

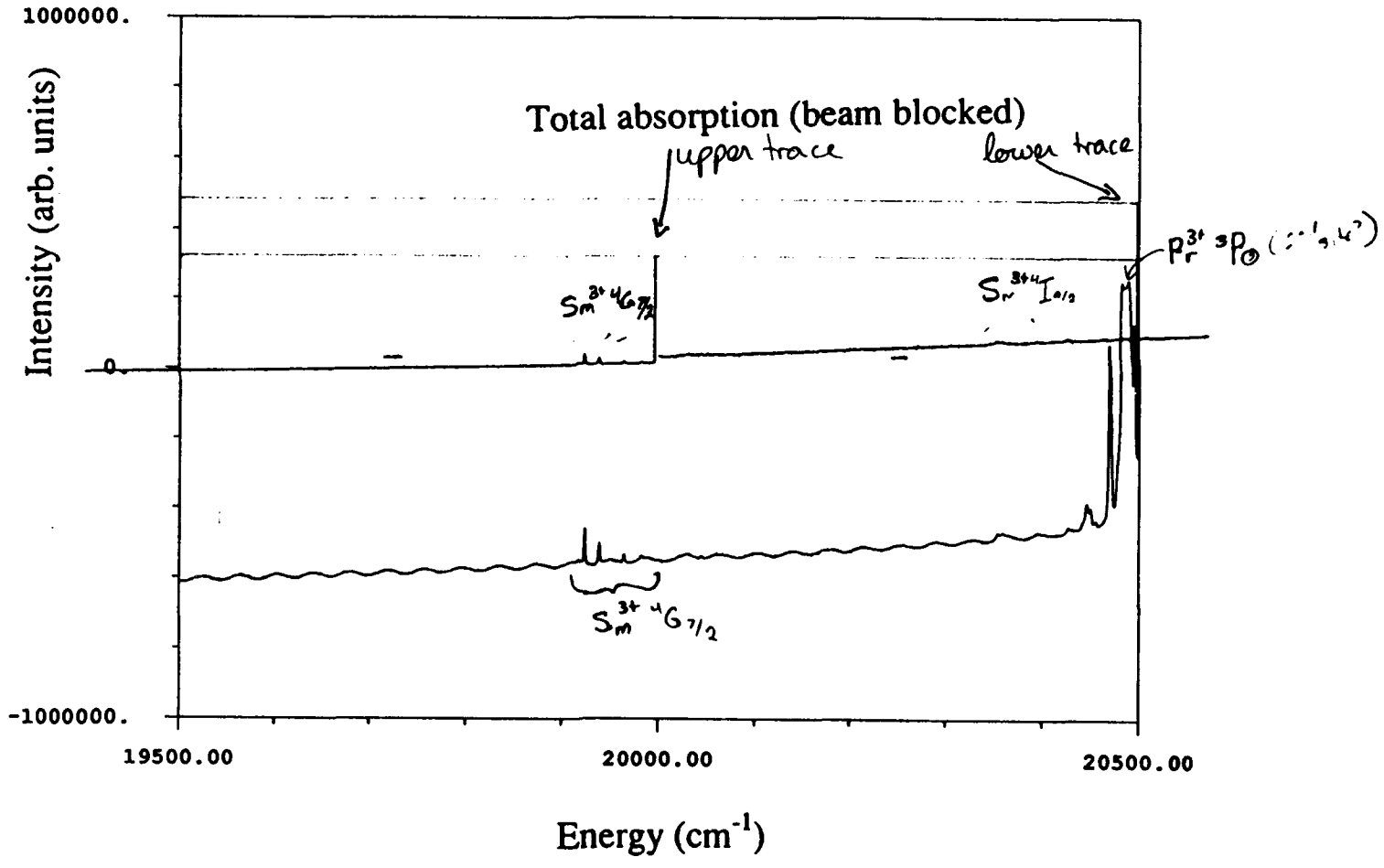
Absorption Spectra
Upper trace is $Sm:CaWO_4$
Lower trace is $Pr,Sm:CaWO_4$
Absorption peaks are labeled as identified



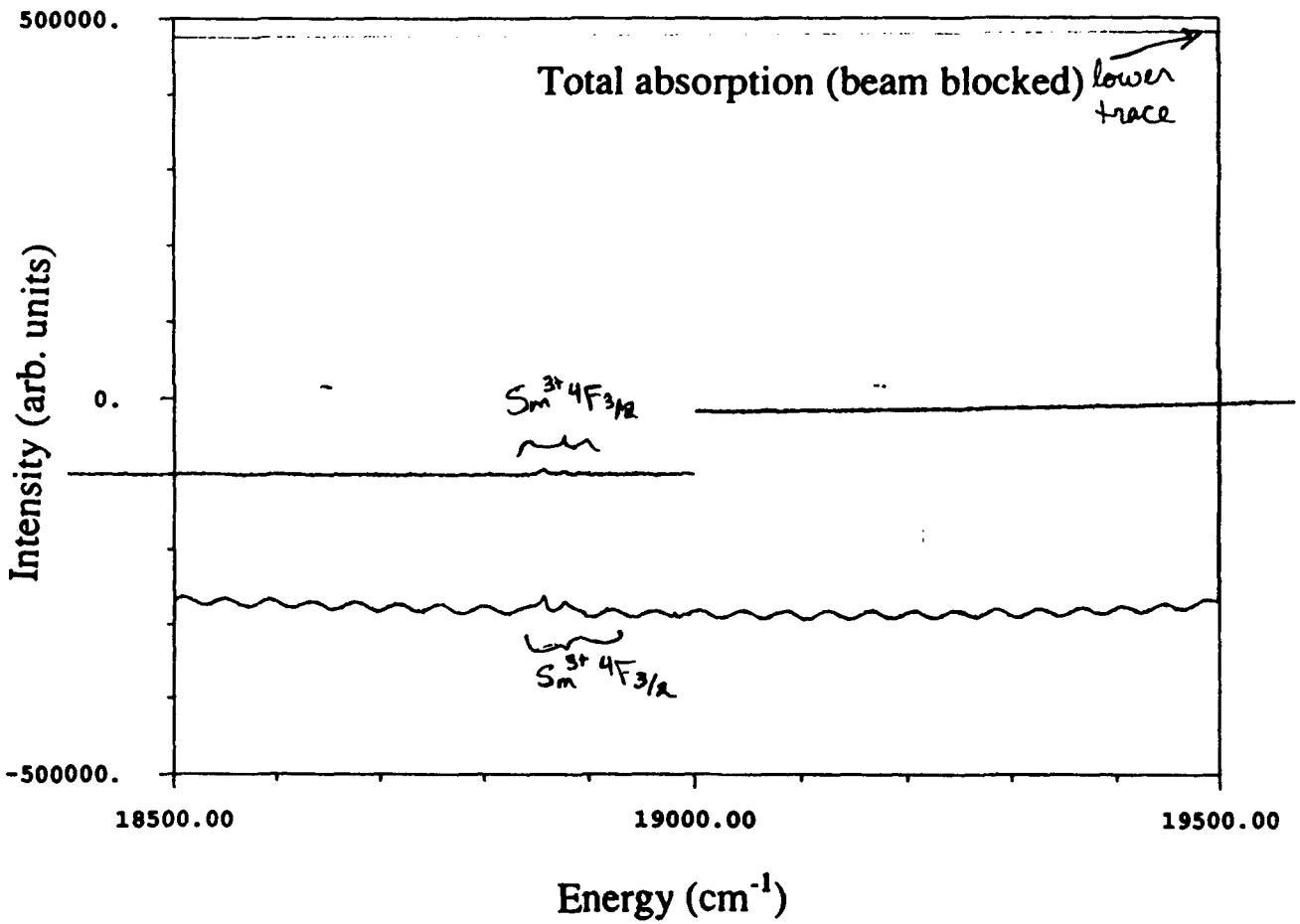
Absorption Spectra
Upper trace is Sm:$CaWO_4$
Lower trace is Pr,Sm:$CaWO_4$
Absorption peaks are labeled as identified



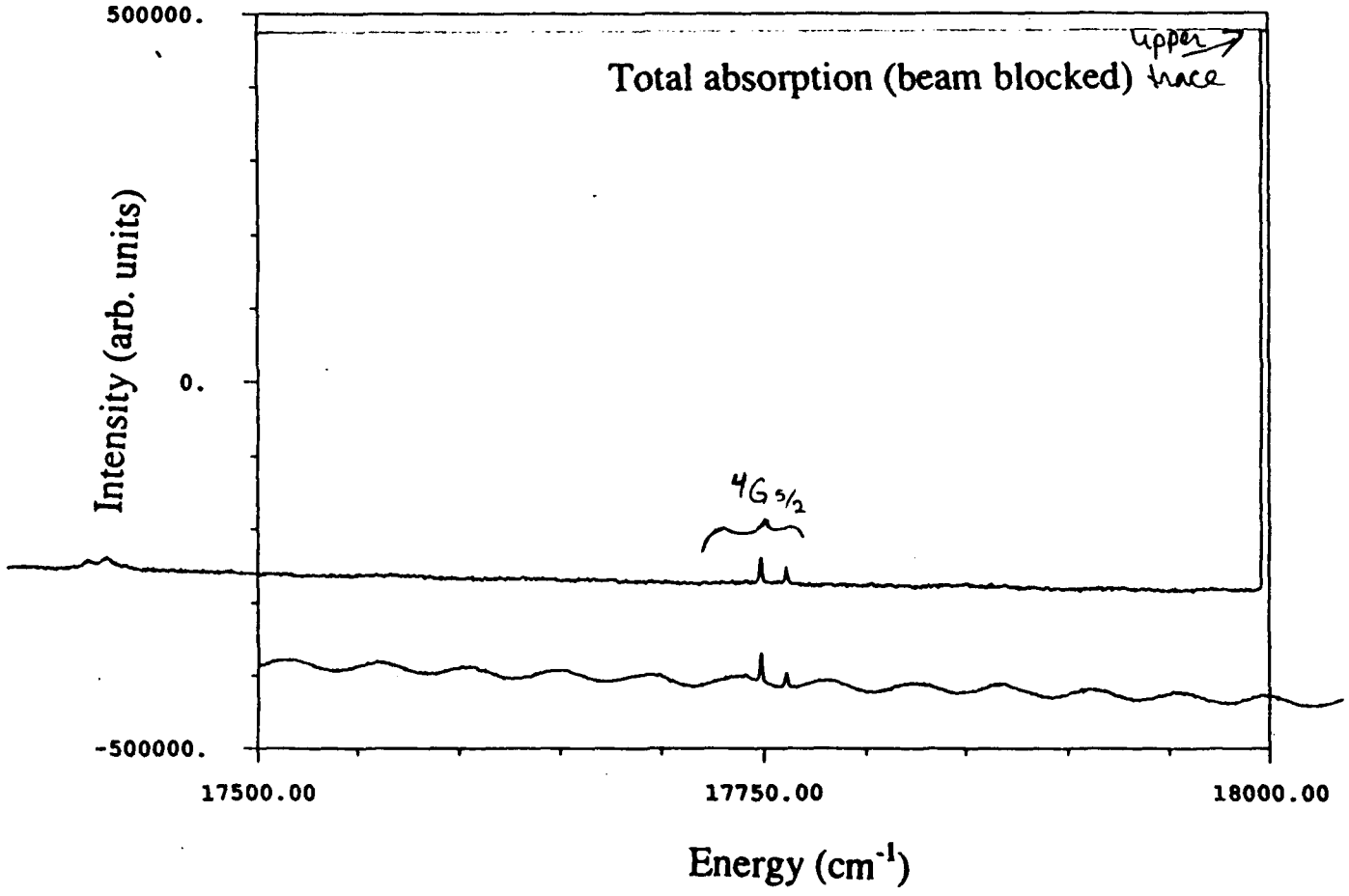
Absorption Spectra
Upper trace is $Sm:CaWO_4$
Lower trace is $Pr,Sm:CaWO_4$
Absorption peaks are labeled as identified



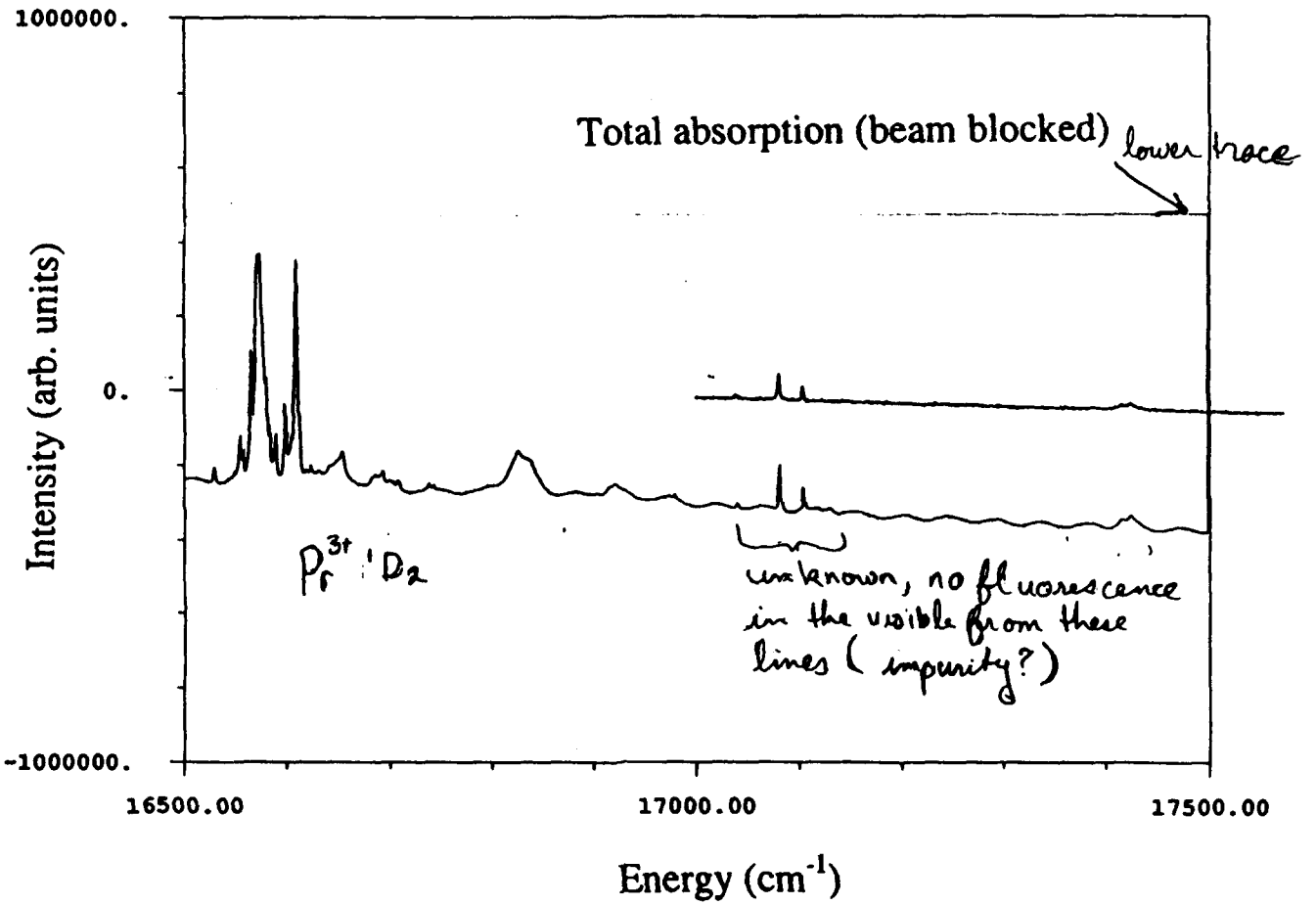
Absorption Spectra
Upper trace is Sm:$CaWO_4$
Lower trace is Pr,Sm:$CaWO_4$
Absorption peaks are labeled as identified



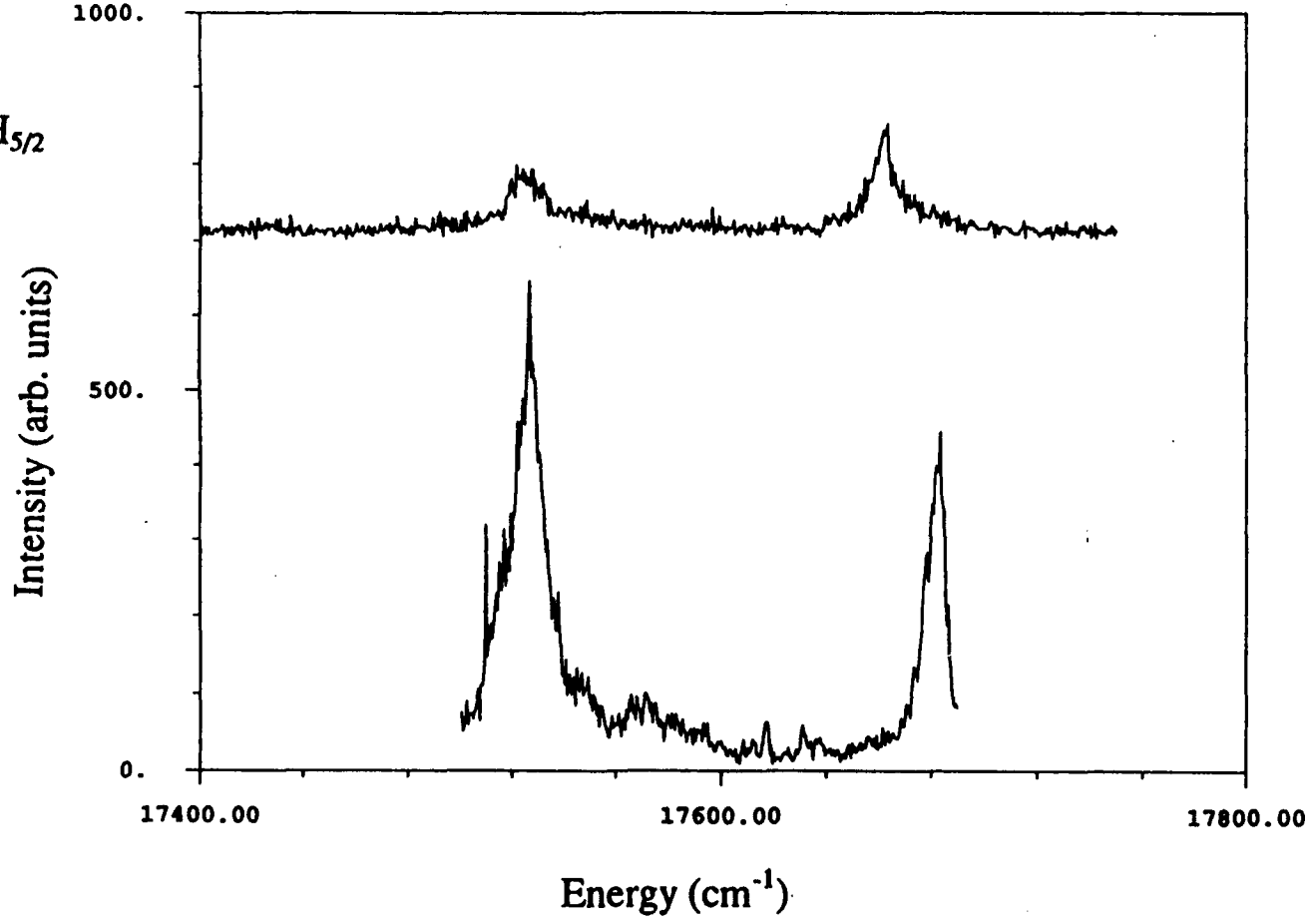
Absorption Spectra
Upper trace is $Sm:CaWO_4$
Lower trace is $Pr,Sm:CaWO_4$
Absorption peaks are labeled as identified



Absorption Spectra
Upper trace is $Sm:CaWO_4$
Lower trace is $Pr,Sm:CaWO_4$
Absorption peaks are labeled as identified

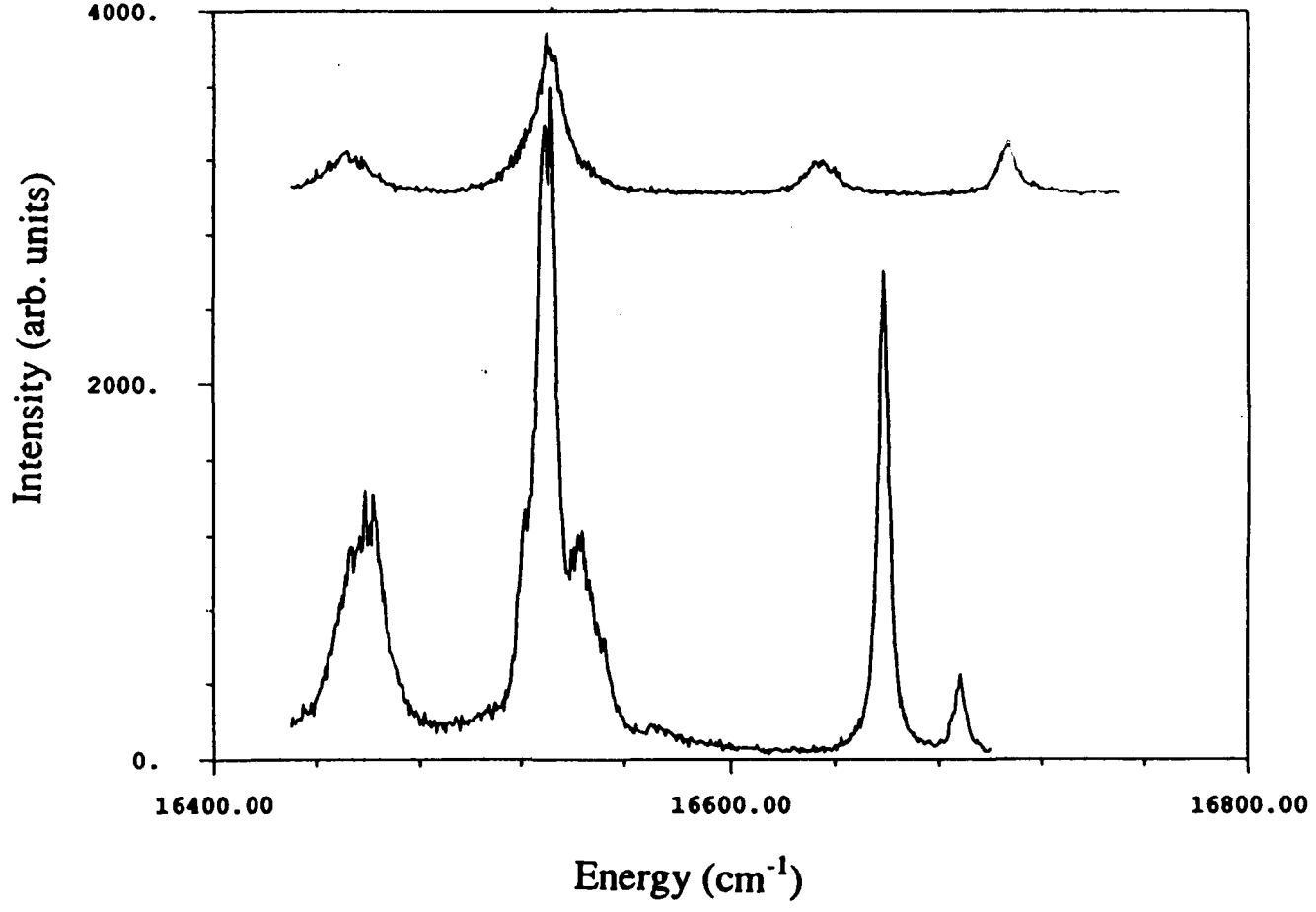


Fluorescence Spectra (1-27-94)
Sm:$CaWO_4$ 0.1% (Sample 5-249)
Upper trace pumped at 17761 cm^{-1}
Lower trace pumped at 17749 cm^{-1}
Data indicates 2 sites

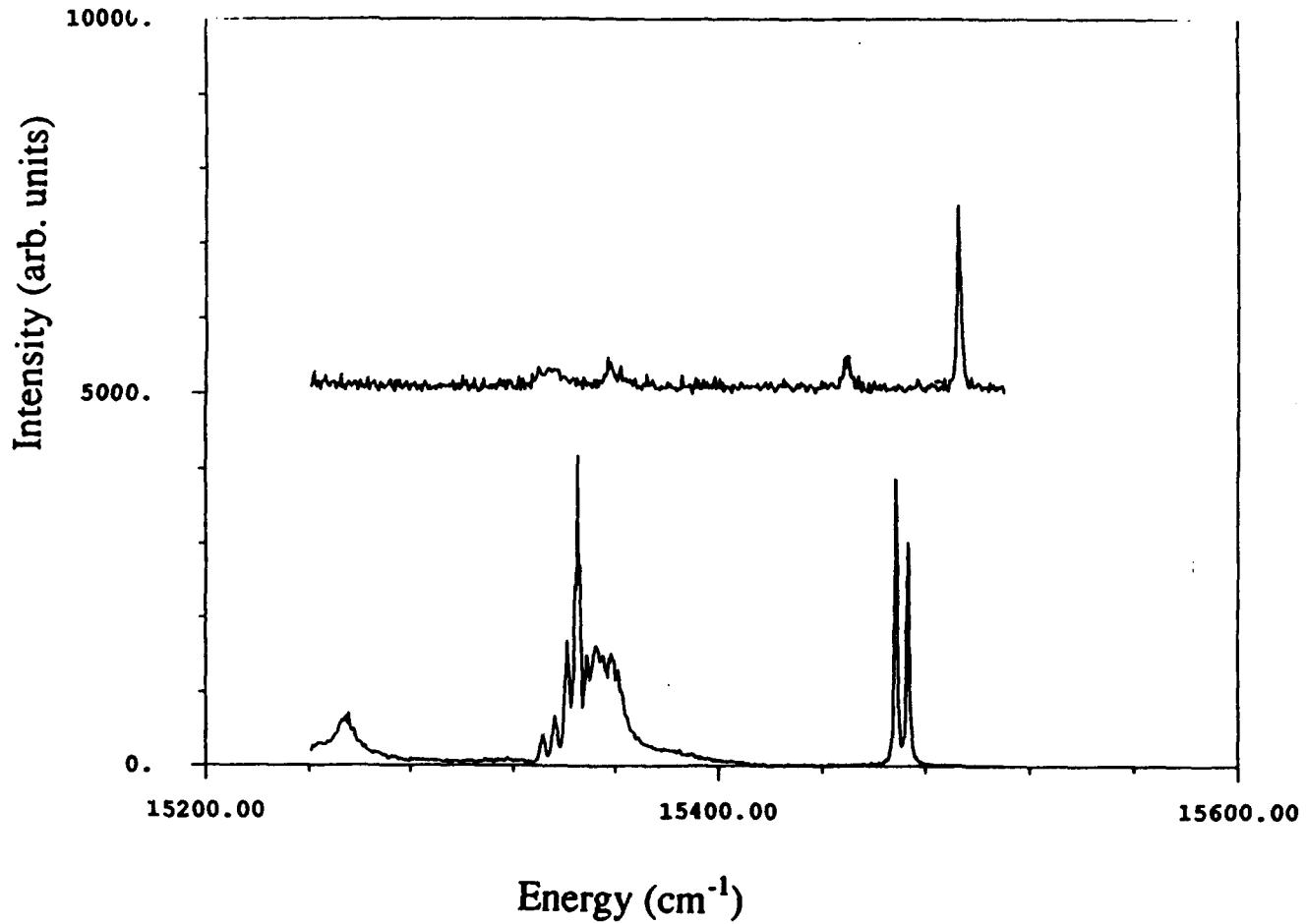


Fluorescence Spectra (1-27-94)
Sm:$CaWO_4$ 0.1% (Sample 5-249)
Upper trace pumped at 17761 cm^{-1}
Lower trace pumped at 17749 cm^{-1}
Data indicates 2 sites

$^6H_{7/2}$



Fluorescence Spectra (1-27-94)
Sm:$CaWO_4$ 0.1% (Sample 5-249)
Upper trace pumped at 17761 cm^{-1} $^6H_{9/2}$
Lower trace pumped at 17749 cm^{-1}
Data indicates 2 sites



Persistent spectral hole burning database project

Development of a database system for titles and abstracts of published research on materials and phenomena for time- and frequency-domain optical memories and optical signal processing based on persistent spectral hole burning has been carried out by the MSU Physics Department group of Rufus Cone. The goal is to create and maintain an up to date list of publications, abstracts, and keywords for easy search and retrieval with IBM PC-compatible software.

We have investigated 52 bibliographic software packages reviewed in Database Magazine. Demonstration versions of several of these packages were tested using 480 sample data files with abstracts that we down-loaded from PINET, a general electronic database published by the American Institute of Physics (AIP). The test files covered research on photon echoes and hole burning and were re-formatted for use in the database using programs written in the C language by Guangming Wang in the MSU group. Test searches on authors, keywords, materials, and phenomena were carried out successfully.

Automatic retrieval of files from larger bibliographic database services such as INSPEC and SCISEARCH also has been investigated. These databases cover far more journals and go back farther in time than smaller cheaper databases like PINET; for example, INSPEC covers from 1969 to the present. The Montana State University library may search these databases using appropriate keywords. Records can be automatically formatted to conform to the import specifications of the IBM PC-compatible bibliography packages.

The first year cost of the full-scale project will be $10,000, with a cost of updating the list in subsequent years estimated at $2,000 per year. These costs are based on an average per record of approximately $0.80 to $1.00 depending on the network service used and an estimated 8,000 or more records required to prepare the initial list covering previous years (preliminary electronic searches indicate there may be even more). To keep the bibliography up to date, the network database services will automatically search monthly using our keywords and then electronically mail the results to our address. The cost of the PC-compatible bibliographic software packages ranges from $200 to $600; a modern 486-66 PC computer is available in the MSU laboratory for this project.

We propose to have the library perform literature searches using keywords provided by us. The downloaded data will be entered into the bibliography database on our laboratory computer. After the initial network search, we will perform periodic network searches of new literature either automatically or as needed in order to insure that the database is up to date.

NOTE:
The MSU Libraries point out that most of the electronic bibliographic services have copyrights that would prohibit us from even giving the database that we compile to other users.

Table I. Effective Ionic Radii (R.D. Shannon Acta Crysta. A 32 751 (1976))

ION	EC	CN	SP	CR	'IR'		ION	EC	CN	SP	CR	'IR'		ION	EC	CN	SP	CR	'IR'	
Ac+3	6p 6	VI		1.26	1.12	R	Cd+2	4d10	IV		.92	.78		Dy+3		VII		1.11	.97	
Ag+1	4d10	II		.81	.67				V		1.01	.87				VIII		1.167	1.027	R
		IV		1.14	1.00	C			VI		1.09	.95				IX		1.223	1.083	R
		IVSQ		1.16	1.02				VII		1.17	1.03	C	Er+3	4f11	VI		1.030	.890	R
		V		1.23	1.09	C			VIII		1.24	1.10	C			VII		1.085	.945	
		VI		1.29	1.15	C			XII		1.45	1.31				VIII		1.144	1.004	R
		VII		1.36	1.22		Ce+3	6s 1	VI		1.15	1.01	R			IX		1.202	1.062	R
		VIII		1.42	1.28				VII		1.21	1.07	E	Eu+2	4f 7	VI		1.31	1.17	
Ag+2	4d 9	IVSQ		.93	.79				VIII		1.283	1.143	R			VII		1.34	1.20	
		VI		1.08	.94				IX		1.336	1.196	R			VIII		1.39	1.25	
Ag+3	4d 8	IVSQ		.81	.67				X		1.39	1.25				IX		1.44	1.30	
		VI		.89	.75	R			XII		1.48	1.34	C			X		1.49	1.35	
Al+3	2p 6	IV		.53	.39	*	Ce+4	5p 6	VI		1.01	.87	R	Eu+3	4f 6	VI		1.087	.947	R
		V		.62	.48				VIII		1.11	.97	R			VII		1.15	1.01	
		VI		.675	.535	R*			X		1.21	1.07				VIII		1.206	1.066	R
Am+2	5f 7	VII		1.35	1.21				XII		1.28	1.14				IX		1.260	1.120	R
		VIII		1.40	1.26		Cf+3	6d 1	VI		1.09	.95	R	F -1	2p 6	II		1.145	1.285	
		IX		1.45	1.31		Cf+4	5f 8	VI		.961	.821	R			III		1.16	1.30	
Am+3	5f 6	VI		1.115	.975	R			VIII		1.06	.92				IV		1.17	1.31	
		VIII		1.23	1.09		Cl-1	3p 6	VI		1.67	1.81	P			VI		1.19	1.33	
Am+4	5f 5	VI		.99	.85	R	Cl+5	3s 2	IIIPY		.26	.12		F +7	1s 2	VI		.22	.08	A
		VIII		1.09	.95		Cl+7	2p 6	IV		.22	.08	*	Fe+2	3d 6	IV	HS	.77	.63	
As+3	4s 2	VI		.72	.58	A			VI		.41	.27	A			IVSQ	HS	.78	.64	
As+5	3d10	IV		.475	.335	R*	Cm+3	5f 7	VI		1.11	.97	R			VI	LS	.75	.61	E
		VI		.60	.46	C*	Cm+4	5f 6	VI		.99	.85	R				HS	.920	.780	R*
At+7	5d10	VI		.76	.62	A			VIII		1.09	.95	R			VIII	HS	1.06	.92	C
Au+1	5d10	VI		1.51	1.37	A	Co+2	3d 7	IV	HS	.72	.58		Fe+3	3d 5	IV	HS	.63	.49	*
Au+3	5d 8	IVSQ		.82	.68				V		.81	.67	C			V		.72	.58	
		VI		.99	.85	A			VI	LS	.79	.65	R			VI	LS	.69	.55	R
Au+5	5d 6	VI		.71	.57					HS	.885	.745	R*				HS	.785	.645	R*
B +3	1s 2	III		.15	.01	*			VIII		1.04	.90				VIII	HS	.92	.78	
		IV		.25	.11	*	Co+3	3d 6	VI	LS	.685	.545	R*	Fe+4	3d 4	VI		.725	.585	R
		VI		.41	.27	C				HS	.75	.61		Fe+6	3d 2	IV		.39	.25	R
Ba+2	5p 6	VI		1.49	1.35		Co+4	3d 5	IV		.54	.40		Fr+1	6p 6	VI		1.94	1.80	A
		VII		1.52	1.38	C			VI	HS	.67	.53	R	Ga+3	3d10	IV		.61	.47	*
		VIII		1.56	1.42		Cr+2	3d 4	VI	LS	.87	.73	E			V		.69	.55	
		IX		1.61	1.47					HS	.94	.80	R			VI		.760	.620	R*
		X		1.66	1.52		Cr+3	3d 3	VI		.755	.615	R*	Gd+3	4f 7	VI		1.078	.938	R
		XI		1.71	1.57		Cr+4	3d+2	IV		.55	.41				VII		1.14	1.00	
		XII		1.75	1.61	C			VI		.69	.55	R			VIII		1.193	1.053	R
Be+2	1s 2	III		.30	.16		Cr+5	3d 1	IV		.485	.345	R			IX		1.247	1.107	RC
		IV		.41	.27	*			VI		.63	.49	ER	Ge+2	4s 2	VI		.87	.73	A
		VI		.59	.45	C			VIII		.71	.57		Ge+4	3d10	IV		.530	.390	*
Bi+3	6s 2	V		1.10	.96	C	Cr+6	3p 6	IV		.40	.26				VI		.670	.530	R*
		VI		1.17	1.03	R*			VI		.58	.44	C	H +1	1s 0	I		-.24	-.38	
		VIII		1.31	1.17	R	Cs+1	5p 6	VI		1.81	1.67				II		-.04	-.18	
Bi+5	5d 10	VI		.90	.76	E			VIII		1.88	1.74		Hf+4	4f14	IV		.72	.58	R
Bk+3	5f 8	VI		1.10	.96	R			IX		1.92	1.78				VI		.85	.71	R
Bk+4	5f 7	VI		.97	.83	R			X		1.95	1.81				VII		.90	.76	
		VIII		1.07	.93	R			XI		1.99	1.85				VIII		.97	.83	
Br-1	4p 6	VI		1.82	1.96	P			XII		2.02	1.88		Hg+1	6s 1	III		1.11	.97	
Br+3	4p 2	IVSQ		.73	.59		Cu+1	3d10	II		.60	.46				VI		1.33	1.19	
Br+5	4s 2	IIIPY		.45	.31				IV		.74	.60	E	Hg+2	5d10	II		.83	.69	
Br+7	3d10	IV		.39	.25				VI		.91	.77	E			IV		1.10	.96	
		VI		.53	.39	A	Cu+2	3d 9	IV		0.71	.57				VI		1.16	1.02	
C +4	1s 2	III		.06	-.08				IVSQ		.71	.57	*			VIII		1.28	1.14	R
		IV		.29	.15	P			V		.79	.65	*	Ho+3	4f10	VI		1.041	.901	R
		VI		.30	.16	A			VI		.87	.73				VIII		1.155	1.015	R
Ca+2	3p 6	VI		1.14	1.00		Cu+3	3d 8	VI	LS	.68	.54				IX		1.212	1.072	R
		VII		1.20	1.06	*	D +1	1s 0	II		.04	-.10				X		1.26	1.12	
		VIII		1.26	1.12	*	Dy+2	4f10	VI		1.21	1.07		I -1	5p 6	VI		2.06	2.20	A
		IX		1.32	1.18				VII		1.27	1.13		I +5	5s 2	IIIPY		.58	.44	*
		X		1.37	1.23	C			VIII		1.33	1.19				VI		1.09	.95	
		XII		1.48	1.34	C	Dy+3	4f 9	VI		1.052	.912	R	I +7	4d10	IV		.56	.42	

I+7		VI		.67	.53		Nb+5	4p 6	IV		.62	.48	C	Pd+2	4d 8	IVSQ		.78	.64			
In+3	4d10	IV		.76	.62				VI		.78	.64				VI		1.00	.86			
		VI		.940	.800	R*			VII		.83	.69	C	Pd+3	4d 7	VI		.90	.76			
		VIII		1.06	.92	RC			VIII		.88	.74		Pd+4	4d 6	VI		.755	.615	R		
Ir+3	5d 6	VI		.82	.68	E	Nd+2	4f 4	VIII		1.43	1.29		Pm+3	4f 4	VI		1.11	.97	R		
Ir+4	5d 5	VI		.765	.625	R			IX		1.49	1.35				VIII		1.233	1.093	R		
Ir+5	5d 4	VI		.71	.57	EM	Nd+3	4f 3	VI		1.123	.983	R			IX		1.284	1.144	R		
K +1	3p 6	IV		1.51	1.37				VIII		1.249	1.109	R*	Po+4	6s 2	VI		1.08	.94	R		
		VI		1.52	1.38				IX		1.303	1.163	R			VIII		1.22	1.08	R		
		VII		1.60	1.46				XII		1.41	1.27	E	Po+6	5d10	VI		.81	.67	A		
		VIII		1.65	1.51		Ni+2	3d 8	IV		.69	.55		Pr+3	4f 2	VI		1.13	.99	R		
		IX		1.69	1.55				IVSQ		.63	.49				VIII		1.266	1.126	R		
		X		1.73	1.59				V		.77	.63	E			IX		1.319	1.179	R		
		XII		1.78	1.64				VI		.830	.690	R*	Pr+4	4f 1	VI		.99	.85	R		
La+3	4d10	VI		1.172	1.032	R	Ni+3	3d 7	VI	LS	.70	.56	R*			VIII		1.10	.96	R		
		VII		1.24	1.10					HS	.74	.60	E	Pt+2	5d 8	IVSQ		.74	.60			
		VIII		1.300	1.160	R	Ni+4	3d 6	VI	LS	.62	.48	R			VI		.94	.80	A		
		IX		1.356	1.216	R	No+2	5f14	VI		1.24	1.1	E	Pt+4	5d 6	VI		.765	.625	R		
		X		1.41	1.27		Np+2	5f 5	VI		1.24	1.10		Pt+5	5d 5	VI		.71	.57	ER		
		XII		1.50	1.36	C	Np+3	5f 4	VI		1.15	1.01	R	Pu+3	5f 5	VI		1.14	1.00	R		
Li+1	1s 2	IV		.730	.590	*	Np+4	5f 3	VI		1.01	.87	R	Pu+4	5f 4	VI		1.00	.86	R		
		VI		.90	.76	*			VIII		1.12	.98	R			VIII		1.10	.96			
		VIII		1.06	.92	C	Np+5	5f 2	VI		.89	.75		Pu+5	5f 3	VI		.88	.74	E		
Lu+3	4f14	VI		1.001	.861	R	Np+6	5f 1	VI		.86	.72	R	Pu+6	5f 2	VI		.85	.71	R		
		VIII		1.117	.977	R	Np+7	6p 6	VI		.85	.71	A	Ra+2	6p 6	VIII		1.62	1.48	R		
		IX		1.172	1.032	R	O-2	2p 6	II		1.21	1.35				XII		1.84	1.70	R		
Mg+2	2p 6	IV		.71	.57				III		1.22	1.36		Rb+1	4p 6	VI		1.66	1.52			
		V		.80	.66				IV		1.24	1.38				VII		1.70	1.56			
		VI		.860	.720	*			VI		1.26	1.40				VIII		1.75	1.61			
		VIII		1.03	.89	C			VIII		1.28	1.42				IX		1.77	1.63	E		
MN+2	3d 5	IV	HS	.80	.66		Oh-1		II		1.18	1.32				X		1.80	1.66			
		V	HS	.89	.75	C			III		1.20	1.34				XI		1.83	1.69			
		VI	LS	.81	.67	E			IV		1.21	1.35	E			XII		1.86	1.72			
			HS	.970	.830	R*			VI		1.23	1.37	E			XIV		1.97	1.83			
		VII	HS	1.04	.90	C	Os+4	5d 4	VI		.770	.630	RM	Re+4	5d 3	VI		.77	.63	RM		
		VIII		1.10	.96	R	Os+5	5d 3	VI		.715	.575	E	Re+5	5d 2	VI		.72	.58	E		
Mn+3	3d 4	V		.72	.58		Os+6	5d 2	V		.63	.49		Re+6	5d 1	VI		.69	.55	E		
		VI	LS	.72	.58	R			VI		.685	.545	E	Re+7	5p 6	IV		.52	.38			
			HS	.785	.645	R*	Os+7	5d 1	VI		.665	.525	E			VI		.67	.53			
Mn+4	3d 3	IV		.53	.39	R	Os+8	5p 6	IV		.53	.39		Rh+3	4d 6	VI		.805	.665	R		
		VI		.670	.530	R*	P +3	3s 2	VI		.58	.44	A	Rh+4	4d 5	VI		.74	.60	RM		
Mn+5	3d 2	IV		.47	.33	R	P +5	2p 6	IV		.31	.17	*	Rh+5	4d 4	VI		.69	.55			
Mn+6	3d 1	IV		.395	.255				V		.43	.29		Ru+3	4d 5	VI		.82	.68			
Mn+7	3p 6	IV		.39	.25				VI		.52	.38	C	Ru+4	4d 4	VI		.760	.620	RM		
		VI		.60	.46	A	Pa+3	5f 2	VI		1.18	1.04	E	Ru+5	4d 3	VI		.705	.565	ER		
Mo+3	4d 3	VI		.83	.69	E	Pa+4	6d 1	VI		1.04	.90	R	Ru+7	4d 1	IV		.52	.38			
Mo+4	4d 2	VI		.790	.650	RM			VIII		1.15	1.01		Ru+8	4p 6	IV		.50	.36			
Mo+5	4d 1	IV		.60	.46	R			VII		1.16	1.02	E	S -2	3p 6	VI		1.70	1.84	P		
		VI		.75	.61	R			VIII		1.219	1.079	R	S +4	3s 2	VI		.51	.37	A		
Mo+6	4p 6	IV		.55	.41	R*			IX		1.272	1.132	R	S+6	2p 6	IV		.26	.12	*		
		V		.64	.50				XII		1.38	1.24	C			VI		.43	.29	C		
		VI		.73	.59	R*	Pa+5	6p 6	VI		.92	.78		Sb+3	5s 2	IVPY		.90	.76			
		VII		.87	.73				VIII		1.05	.91				V		.94	.80			
N -3	2p 6	IV		1.32	1.46				IX		1.09	.95				VI		.90	.76	A		
N +3	2s 2	VI		.30	.16	A	Pb+2	6s2	IVPY		1.12	.98	C	Sb+5	4d10	VI		.74	.60	*		
N +5	1s 2	III		.044	-.104				VI		1.33	1.19		Sc+3	3p 6	VI		.885	.745	R*		
		VI		.27	.13	A			VII		1.37	1.23	C			VIII		1.010	.870	R*		
Na+1	2p 6	IV		1.13	.99				VIII		1.43	1.29	C	Se-2	4p 6	VI		1.84	1.98	P		
		V		1.14	1.00				IX		1.49	1.35	C	Se+4	4s 2	VI		.64	.50	A		
		VI		1.16	1.02				X		1.54	1.40	C	Se+6	3d10	IV		.42	.28	*		
		VII		1.26	1.12				XI		1.59	1.45	C			VI		.56	.42	C		
		VIII		1.32	1.18				XII		1.63	1.49		Si+4	2p 6	IV		.40	.26	*		
		IX		1.38	1.24	C	Pb+4	5d10	IV		.79	.65	E			VI		.540	.400	R*		
		XII		1.53	1.39				V		.87	.73	E	Sm+2	4f 6	VII		1.36	1.22			
Nb+3	4d 2	VI		.86	.72				VI		.915	.775	R			VIII		1.41	1.27			
Nb+4	4d 1	VI		.82	.68	RE			VIII		1.08	.94	R			IX		1.46	1.32			
		VIII		.93	.79		Pd+1	4d 9	II		.73	.59		Sm+3	4f 5	VI		1.098	.958	R		

Sn+4	4d10	IV	.69	.55	R			VIII	1.00	.86	
		V	.76	.62	C	V +2	3d 3	VI	.93	.79	
		VI	.830	.690	R*	V +3	3d 2	VI	.780	.640	R*
		VII	.89	.75		V +4	3d 1	V	.67	.53	
		VIII	.95	.81	C			VI	.72	.58	R*
Sr+2	4p 6	VI	1.32	1.18				VIII	.86	.72	E
		VII	1.35	1.21		V +5	3p 6	IV	.495	.355	R*
		VIII	1.40	1.26				V	.60	.46	*
		IX	1.45	1.31				VI	.68	.54	
		X	1.50	1.36	C	W +4	5d 2	VI	.80	.66	RM
		XII	1.58	1.44	C	W +5	5d 1	VI	.76	.62	R
Ta+3	5d 2	VI	.86	.72	E	W+6	5p 6	IV	.56	.42	*
Ta+4	5d 1	VI	.82	.68	E			V	.65	.51	
Ta+5	5p 6	VI	.78	.64				VI	.74	.60	*
		VII	.83	.69		Xe+8	4d10	IV	.54	.40	
		VIII	.88	.74				VI	.62	.48	
Tb+3	4f 8	VI	1.063	.923	R	Y +3	4p 6	VI	1.040	.900	R*
		VII	1.12	.98	E			VII	1.10	.96	
		VIII	1.180	1.040	R			VIII	1.159	1.019	R*
		IX	1.235	1.095	R			IX	1.215	1.075	R
Tb+4	4f 7	VI	.90	.76	R	Yb+2	4f14	VI	1.16	1.02	
		VIII	1.02	.88				VII	1.22	1.08	E
Tc+4	4d 3	VI	.785	.645	RM			VIII	1.28	1.14	
Tc+5	4d 2	VI	.74	.60	ER	Yb+3	4f13	VI	1.008	.868	R*
Tc+7	4p 6	IV	.51	.37				VII	1.065	.925	E
		VI	.70	.56	A			VIII	1.125	.985	R
Te-2	5p 6	VI	2.07	2.21	P			IX	1.182	1.042	R
Te+4	5s 2	III	.66	.52		Zn+2	3d10	IV	.74	.60	*
		IV	.80	.66				V	.82	.68	*
		VI	1.11	.97				VI	.880	.740	R*
Te+6	4d10	IV	.57	.43	C			VIII	1.04	.90	C
		VI	.70	.56	*	Zr+4	4p 6	IV	.73	.59	R
Th+4	6p 6	VI	1.08	.94	C			V	.80	.66	C
		VIII	1.19	1.05	RC			VI	.86	.72	R*
		IX	1.23	1.09	*			VII	.92	.78	*
		X	1.27	1.13	E			VIII	.98	.84	*
		XI	1.32	1.18	C			IX	1.03	.89	
		XII	1.35	1.21	C						
Ti+2	3d 2	VI	1.00	.86	E						
Ti+3	3d 1	VI	.810	.670	R*						
Ti+4	3p 6	IV	.56	.42	C						
		V	.65	.51	C						
		VI	.745	.605	R*						
		VIII	.88	.74	C						
Tl+1	6s 2	VI	1.64	1.50	R						
		VIII	1.73	1.59	R						
		XII	1.84	1.70	RE						
Tl+3	5d10	IV	.89	.75							
		VI	1.025	.885	R						
		VIII	1.12	.98	C						
Tm+2	4f13	VI	1.17	1.03							
		VII	1.23	1.09							
Tm+3	4f12	VI	1.020	.880	R						
		VIII	1.134	.994	R						
		IX	1.192	1.052	R						
U +3	5f 3	VI	1.165	1.025	R						
U +4	5f 2	VI	1.03	.89							
		VII	1.09	.95	E						
		VIII	1.14	1.00	R*						
		IX	1.19	1.05							
		XII	1.31	1.17	E						
U +5	5f 1	VI	.90	.76							
		VII	.98	.84	E						
U +6	6p 6	II	.59	.45							
		IV	.66	.52							
		VI	.87	.73	*						
		VII	.95	.81	E						

Appendix E

Table of isotopes of the elements and their magnetic moments
Kenneth Lee and Weston A. Anderson (1967)
in CRC Handbook of Chemistry and Physics, 66th ed. CRC Press

Z	Isotope El	A	radio-active ?	Spin I	Natural Abundance %	Magnetic Moment μ (eh/4πMc)	Electric Quadrupole Moment Q (10^{-24} cm^2)
0	n	1	*	1/2	--	-1.91315	--
1	H	1		1/2	99.985	2.79268	--
1	H	2		1	1.5×10^{-2}	0.857387	2.73×10^{-3}
1	H	3	*	1/2	--	2.97877	--
2	He	3		1/2	1.3×10^{-4}	-2.1274	--
2	He	4		0	99.99986		
3	Li	6		1	7.42	0.82192	6.9×10^{-4}
3	Li	7		3/2	92.58	3.2560	-3×10^{-2}
3	Li	8	*	2	--	1.653	
4	Be	9		3/2	100	-1.1774	5.2×10^{-2}
5	B	10		3	19.58	1.8007	7.4×10^{-2}
5	B	11		3/2	80.42	2.6880	3.55×10^{-2}
6	C	12		0	98.90		
6	C	13		1/2	1.108	0.702199	--
7	N	13	*	1/2	--	(-)0.322	--
7	N	14		1	99.63	0.40347	1.6×10^{-2}
7	N	15		1/2	0.37	-0.28298	--
8	O	15	*	1/2	--	0.719	--
8	O	16		0	99.762		
8	O	17		5/2	3.7×10^{-2}	-1.8930	-2.6×10^{-2}
8	O	18		0	0.2		
9	F	17	*	5/2	--	4.720	
9	F	19		1/2	100	2.62727	--
9	F	20	*	2	--	2.093	
10	Ne	19	*	(1/2)	--	-1.886	
10	Ne	20		0	90.51		
10	Ne	21		3/2	0.257	-0.66140	
10	Ne	22		0	9.22		
11	Na	21	*	3/2	--	2.3861	
11	Na	22	*	3	--	1.746	
11	Na	23		3/2	100	2.2161	0.14-0.15
11	Na	24	*	4	--	1.690	
12	Mg	24		0	78.99		
12	Mg	25		5/2	10.13	-0.85449	
12	Mg	26		0	11.01		
13	Al	27		5/2	100	3.6385	0.149
14	Si	28		0	92.23		
14	Si	29		1/2	4.70	-0.5547,	--
14	Si	30		0	3.10		
15	P	31		1/2	100	1.1305	--
15	P	32	*	1	--	-0.2523	
16	S	32		0	95.02		
16	S	33		3/2	0.76	0.64257	-6.4×10^{-2}
16	S	34		0	4.21		

16	S	35	*	3/2	--	1.00	4.54×10^{-2}
16	S	36		0	0.02		
17	Cl	35		3/2	75.53	0.82091	-7.89×10^{-2}
17	Cl	36	*	2	--	1.2838	-1.72×10^{-2}
17	Cl	37		3/2	24.47	0.6833	-6.21×10^{-2}
18	Ar	36		0	0.337		
18	Ar	37	*	3/2	--	1.0	
18	Ar	38		0	0.63		
18	Ar	40		0	99.60		
19	K	38	*	3	--	1.374	
19	K	39		3/2	93.10	0.39097	0.11
19	K	40	*	4	1.18×10^{-2}	-1.296	
19	K	41		3/2	6.88	0.21459	
19	K	42	*	2	--	-1.140	
19	K	43	*	3/2	--	0.163	
20	Ca	40		0	96.914		
20	Ca	41	*	7/2	--	-1.5924	
20	Ca	42		0	0.647		
20	Ca	43		7/2	0.145	-1.3153	
20	Ca	44		0	2.086		
20	Ca	46		0	0.004		
20	Ca	48		0	0.187		
21	Sc	43	*	7/2	--	4.61	-0.26
21	Sc	44	*	2	--	2.56	0.14
21	Sc	44	*	6	--	3.96	0.37
21	Sc	45		7/2	100	4.7492	-0.22
21	Sc	46	*	4	--	3.03	0.12
21	Sc	47	*	7/2	--	5.33	-0.22
22	Ti	45	*	7/2	--	0.095	1.5×10^{-2}
22	Ti	46		0	8.0		
22	Ti	47		5/2	7.28	-0.78710	
22	Ti	48		0	73.8		
22	Ti	49		7/2	5.51	-1.1022	
22	Ti	50		0	5.4		
23	V	49	*	7/2	--	4.46	
23	V	50		6	0.24	3.3413	
23	V	51		7/2	99.76	5.139	-4×10^{-2}
24	Cr	50		0	4.35		
24	Cr	52		0	83.79		
24	Cr	53		3/2	9.55	-0.47354	
24	Cr	54		0	2.36		
25	Mn	52	*	6	--	3.075	
25	Mn	52	*	2	--	0.008	
25	Mn	53	*	7/2	--	5.05	
25	Mn	54	*	(2)(3)	--	(2.2)(2.6)	
25	Mn	55		5/2	100	3.444	0.55
25	Mn	56	*	3	--	3.240	
26	Fe	54		0	5.8		
26	Fe	56		0	91.72		
26	Fe	57		1/2	2.19	0.09024	--
26	Fe	58		0	0.28		
27	Co	55	*	7/2	--	4.6	
27	Co	56	*	4	--	3.85	
27	Co	57	*	7/2	--	4.65	

27	Co	58	*	2	--	4.05	
27	Co	59		7/2	100	4.6163	0.40
27	Co	60	*	5	--	3.800	
28	Ni	58		0	68.27		
28	Ni	60		0	26.10		
28	Ni	61		3/2	1.19	-0.74868	
28	Ni	62		0	3.59		
28	Ni	64		0	0.91		
29	Cu	61	*	3/2	--	2.13	
29	Cu	63		3/2	69.09	2.2206	-0.16
29	Cu	64	*	1	--	0.40	
29	Cu	65		3/2	30.91	2.3789	-0.15
29	Cu	66	*	1	--	-0.216	
30	Zn	64		0	48.6		
30	Zn	65	*	5/2	--	0.7692	-2.4×10^{-2}
30	Zn	66		0	27.9		
30	Zn	67		5/2	4.11	0.8733	0.15
30	Zn	68		0	18.8		
30	Zn	70		0	0.6		
31	Ga	68	*	1	--	0.0117	3.1×10^{-2}
31	Ga	69		3/2	60.4	2.011	0.178
31	Ga	71		3/2	39.6	2.5549	0.112
31	Ga	72	*	3	--	-0.13220	0.72
32	Ge	70		0	20.5		
32	Ge	71	*	1/2	--	0.55	--
32	Ge	72		0	27.4		
32	Ge	73		9/2	7.76	-0.87679	-0.2
32	Ge	74		0	36.5		
32	Ge	76		0	7.8		
33	As	75		3/2	100	1.4349	0.3
33	As	76	*	2	--	-0.906	
34	Se	74		0	0.9		
34	Se	76		0	9.0		
34	Se	77		1/2	7.58	0.5325	--
34	Se	78		0	23.5		
34	Se	79		7/2	--	-1.02	0.9
34	Se	80		0	49.6		
34	Se	82		0	9.4		
35	Br	76	*	1	--	(-)0.548	0.27
35	Br	79		3/2	50.54	2.0990	0.33
35	Br	80	*	1	--	0.514	0.20
35	Br	80m	*	5	--	1.317	0.76
35	Br	81		3/2	49.46	2.2626	0.28
35	Br	82	*	5	--	(+)1.626	(+)0.76
36	Kr	78		0	0.35		
36	Kr	80		0	2.25		
36	Kr	82		0	11.6		
36	Kr	83		9/2	11.55	-0.9671	0.15
36	Kr	84		0	57.0		
36	Kr	85	*	9/2	--	-1.001	0.25
36	Kr	86		0	17.3		
37	Rb	81	*	3/2	--	2.05	
37	Rb	82m	*	5	--	1.50	
37	Rb	83	*	5/2	--	1.42	

37	Rb	84	*	2	--	-1.32	
37	Rb	85		5/2	72.15	1.3482	0.27
37	Rb	86	*	2	--	-1.69	
37	Rb	87		3/2	27.85	2.7414	0.13
38	Sr	84		0	0.56		
38	Sr	86		0	9.86		
38	Sr	87		9/2	7.02	-1.0893	0.2
38	Sr	88		0	82.58		
39	Y	89		1/2	100	-0.13682	--
39	Y	90	*	2	--	-1.62	-0.16
39	Y	91	*	1/2	--	0.163	--
40	Zr	90		0	51.45		
40	Zr	91		5/2	11.23	-1.30284	
40	Zr	92		0	17.17		
40	Zr	94		0	17.33		
40	Zr	96		0	2.78		
41	Nb	93		9/2	100	6.1435	-0.2
42	Mo	92		0	14.84		
42	Mo	94		0	9.25		
42	Mo	95		5/2	15.72	0.9097	0.12
42	Mo	96		0	15.92		
42	Mo	97		5/2	9.46	-0.9289	1.1
42	Mo	98		0	16.68		
42	Mo	100		0	24.13		
43	Tc	99	*	9/2	--	5.6572	0.3
44	Ru	96		0	5.52		
44	Ru	98		0	1.88		
44	Ru	99		5/2	12.72	-0.6430	
44	Ru	100		0	12.6		
44	Ru	101		5/2	17.07	-0.7207	
44	Ru	102		0	31.6		
44	Ru	104		0	18.7		
45	Rh	103		1/2	100	-0.08790	--
46	Pd	102		0	1.02		
46	Pd	104		0	11.14		
46	Pd	105		5/2	22.23	-0.639	
46	Pd	106		0	+27.33		
46	Pd	108		0	26.46		
46	Pd	110		0	11.72		
47	Ag	104	*	5	--	4.0	
47	Ag	104m	*	2	--	3.7	
47	Ag	105	*	1/2	--	0.101	--
47	Ag	107		1/2	51.82	-0.11301	
47	Ag	108	*	1	--	4.2	
47	Ag	109		1/2	48.18	-0.12992	
47	Ag	110m	*	6	--	3.587	
47	Ag	111	*	1/2	--	-0.145	
47	Ag	112	*	2	--	0.0545	
47	Ag	113	*	1/2	--	0.158	
48	Cd	106		0	1.25		
48	Cd	107	*	5/2	--	-0.6162	0.8
48	Cd	108		0	0.89		
48	Cd	109	*	5/2	--	-0.8293	0.8
48	Cd	110		0	?12.49?		

48	Cd	111		1/2	12.75	--0.5922	--
48	Cd	112		0	24.13		
48	Cd	113		1/2	12.26	-0.6195	--
48	Cd	113m	*	11/2	--	-1.09	-0.79
48	Cd	114		0	28.73		
48	Cd	115	*	1/2	--	-0.649	--
48	Cd	115m	*	11/2	--	-1.044	-0.61
48	Cd	116		0	7.49		
49	In	113		9/2	4.28	5.4960	1.14
49	In	113m	*	1/2	--	-0.2105	--
49	In	114m	*	5	--	4.7	
49	In	115	*	9/2	95.72	5.5079	1.16
49	In	115m	*	1/2	--	-0.2437	--
49	In	116	*	5	--	4.21	
49	In	116m	*	5	--	4.4	
50	Sn	112		0	1.0		
50	Sn	114		0	0.7		
50	Sn	115		1/2	0.35	-0.91320	--
50	Sn	116		0	14.7		
50	Sn	117		1/2	7.61	-0.99490	--
50	Sn	118		0	24.3		
50	Sn	119		1/2	8.58	-1.0409	--
50	Sn	120		0	32.4		
50	Sn	122		0	4.6		
50	Sn	124		0	5.66		
51	Sb	121		5/2	57.25	3.3415	-0.5
51	Sb	122	*	2	--	-1.90	
51	Sb	123		7/2	42.75	2.5334	-0.7
52	Te	119	*	1/2	--	0.27	--
52	Te	120		0	0.096		
52	Te	122		0	2.60		
52	Te	123		1/2	0.87	-0.7319	--
52	Te	124		0	4.816		
52	Te	125		1/2	6.99	-0.8824.	--
52	Te	126		0	18.95		
52	Te	128		0	31.69		
52	Te	130		0	33.80		
53	I	125	*	5/2	--	3	-0.66
53	I	127		5/2	100	2.7937	-0.69
53	I	129	*	7/2	--	2.6031	-0.48
53	I	131	*	7/2	--	2.738	-0.41
54	Xe	124		0	0.10		
54	Xe	126		0	0.09		
54	Xe	128		0	1.91		
54	Xe	129		1/2	26.44	-0.77247	--
54	Xe	130		0	4.1		
54	Xe	131		3/2	21.18	0.68697	-0.12
54	Xe	132		0	26.9		
54	Xe	134		0	10.4		
54	Xe	136		0	8.9		
55	Cs	127	*	1/2	--	1.4.3	--
55	Cs	129	*	1/2	--	1.47	--
55	Cs	130	*	1	--	1.4	
55	Cs	131	*	5/2	--	3.517	

55	Cs	132	*	2	--	2.22	
55	Cs	133		7/2	100	2.56422	$-3x10^{-3}$
55	Cs	134	*	4	--	2.973	0.43
55	Cs	134m	*	8	--	1.0964	
55	Cs	135	*	7/2	--	2.7134	
55	Cs	137	*	7/2	--	2.8219	
56	Ba	130		0	0.106		
56	Ba	132		0	0.101		
56	Ba	134		0	2.417		
56	Ba	135		3/2	6.59	0.83229	0.25
56	Ba	136		0	7.854		
56	Ba	137		3/2	11.32	0.93107	0.2
56	Ba	138		0	71.70		
57	La	138	*	5	0.089	3.6844	2.7
57	La	139		7/2	99.911	2.7615	0.21
58	Ce	136		0	0.19		
58	Ce	137	*	3/2	--	0.9	
58	Ce	137m	*	11/2	--	0.69	
58	Ce	138		0	0.25		
58	Ce	139	*	3/2	--	1.0	
58	Ce	140		0	88.48		
58	Ce	141	*	7/2	--	0.97	
58	Ce	142		0	11.08		
58	Ce	143	*	7/2	--	1.0	
59	Pr	141		5/2	100	4.09	$-5.9x10^{-2}$
59	Pr	142	*	2	--	0.30	$4x10^{-2}$
60	Nd	142		0	27.13		
60	Nd	143		7/2	12.17	-1.063	-0.48
60	Nd	144		0	23.80		
60	Nd	145		7/2	8.30	-0.654	-0.25
60	Nd	146		0	17.19		
60	Nd	147	*	5/2	--	0.579	
60	Nd	148		0	5.76		
60	Nd	150		0	5.64		
61	Pm	143	*	(5/2)(7/2)	--	(3.8)(3.9)	
61	Pm	144	*	(5)(6)	--	(1.7)(1.8)	
61	Pm	147	*	7/2	--	2.58	0.7
61	Pm	148	*	1	--	2.1	0.2
61	Pm	148m	*	6	--	1.8	
61	Pm	149	*	7/2	--	3.3	
61	Pm	151	*	5/2	--	1.8	1.9
62	Sm	144		0	3.1		
62	Sm	147		7/2	14.97	-0.807	-0.208
62	Sm	148		0	11.3		
62	Sm	149		7/2	13.83	-0.643	$6.0x10^{-2}$
62	Sm	150		0	7.4		
62	Sm	152		0	26.7		
62	Sm	154		0	22.7		
63	Eu	151		5/2	47.82	3.4630	1.16
63	Eu	152	*	3	--	1.912	
63	Eu	153		5/2	52.18	1.5292	2.9
63	Eu	154	*	3	--	2.001	
64	Gd	152		0	0.20		
64	Gd	154		0	2.18		

64	Gd	155		3/2	14.73	-0.32	1.6
64	Gd	156		0	20.47		
64	Gd	157		3/2	15.68	-0.40	2
64	Gd	158		0	24.84		
64	Gd	160		0	21.86		
65	Tb	156	*	3	--	1.5	1.4
65	Tb	159		3/2	100	1.90	1.3
65	Tb	160	*	3	--	1.6	1.9
66	Dy	155	*	(3/2)	--	0.21	
66	Dy	156		0	0.06		
66	Dy	157	*	(3/2)	--	0 32	
66	Dy	158		0	0.10		
66	Dy	160		0	2.34		
66	Dy	161		5/2	18.88	-0.46	1.4
66	Dy	162		0	25.59		
66	Dy	163		5/2	24.97	0.64	1.6
66	Dy	164		0	28.2		
67	Ho	165		7/2	100	4.01	2.82
68	Er	162		0	0.14		
68	Er	164		0	1.61		
68	Er	165	*	5/2	--	0.65	2.2
68	Er	166		0	33.6		
68	Er	167		7/2	22.94	-0.565	2.83
68	Er	168		0	26.8		
68	Er	169	*	1/2	--	0.51	--
68	Er	170		0	14.9		
68	Er	171	*	5/2	--	0.70	
69	Tm	166	*	2	--	0.05	4.6
69	Tm	169		1/2	100	-0.231	--
69	Tm	170	*	1	--	0.26	0.61
69	Tm	171	*	1/2	--	0.227	--
70	Yb	168		0	0.13		
70	Yb	170		0	3.05		
70	Yb	171		1/2	14.31	0.49188	--
70	Yb	172		0	21.9		
70	Yb	173		5/2	16.13	-0.67755	2.8
70	Yb	174		0	31.8		
70	Yb	175	*	(7/2)	--	-0.15	
70	Yb	176		0	12.7		
71	Lu	175		7/2	97.41	2.23	5.68
71	Lu	176	*	7	2.59	3.1	8.0
71	Lu	177	*	7/2	--	2.22	5.51
72	Hf	174		0	0.16		
72	Hf	176		0	5.2		
72	Hf	177		7/2	18.50	0.61	3
72	Hf	178		0	27.1		
72	Hf	179		9/2	13.75	0.47	3
72	Hf	180		0	35.2		
73	Ta	181		7/2	99.988	2.340	3
74	W	180		0	0.13		
74	W	182		0	26.3		
74	W	183		1/2	14.40	0.116205	--
74	W	184		0	30.67		
74	W	186		0	28.6		

75	Re	185		5/2	37.07	3.1437	2.8
75	Re	186	*	1	--	1.728	
75	Re	187	*	5/2	62.93	3.1759	2.6
75	Re	188	*	1	--	1.777	
76	Os	184		0	0.02		
76	Os	186		0	1.58		
76	Os	187		1/2	1.64	0.06432	--
76	Os	188		0	13.3		
76	Os	189		3/2	16.1	0.65004	0.8
76	Os	190		0	26.4		
76	Os	192		0	41.0		
77	Ir	191		3/2	37.3	0.1440	1.5
77	Ir	193		3/2	62.7	0.1568	1.5
78	Pt	190		0	0.01		
78	Pt	192		0	0.79		
78	Pt	194		0	32.9		
78	Pt	195		1/2	33.8	0.6004	--
78	Pt	196		0	25.3		
78	Pt	198		0	7.2		
79	Au	190	*	1	--	0.065	
79	Au	194	*	1	--	0.073	
79	Au	195	*	3/2	--	0.146	
79	Au	196	*	2	--	0.6	
79	Au	197		3/2	100	0.143489	0.59
79	Au	198	*	2	--	0.5842	
79	Au	199	*	3/2	--	0.2673	
80	Hg	193	*	3/2	--	-0.61	
80	Hg	193m	*	13/2	--	-1.05	1.37
80	Hg	195	*	1/2	--	0.53	--
80	Hg	195m	*	13/2	--	-1.04	1.41
80	Hg	196		0	0.15		
80	Hg	197	*	1/2	--	0.52	--
80	Hg	198		0	10.1		
80	Hg	199		1/2	16.84	0.497859	
80	Hg	200		0	23.1		
80	Hg	201		3/2	13.22	-0.55293	0.50
80	Hg	202		0	29.65		
80	Hg	203	*	5/2	--	0.83	0.5
80	Hg	204		0	6.8		
81	Tl	197	*	1/2	--	1.55	--
81	Tl	199	*	1/2	--	1.57	--
81	Tl	200	*	2	--	(0.15)	
81	Tl	201	*	1/2	--	1.58	--
81	Tl	202	*	2	--	(0.15)	
81	Tl	2O3		1/2	29.50	1.5960	--
81	Tl	2O4	*	2	--	0.089	
81	Tl	205		1/2	70.50	1.6116	--
82	Pb	204		0	1.4		
82	Pb	206		0	24.1		
82	Pb	207		1/2	22.6	0.584284	--
82	Pb	208		0	52.4		
83	Bi	203	*	9/2	--	4.59	-0.64
83	Bi	204	*	6	--	4.25	-0.41
83	Bi	205	*	9/2	--	(5.5)	

83	Bi	206	*	6	--	4.56	-0.19
83	Bi	209	*	9/2	100	4.03896	[illegible]4
83	Bi	210	*	1	--	0.0442	0.13
84	Po	205	*	5/2	--	0.26	0.17
84	Po	207	*	5/2	--	0.27	0.28
89	Ac	227	*	3/2	--	1.1	-1.7
90	Th	229	*	5/2	--	0.4	4.6
90	Th	232		0	100		
91	Pa	231	*	3/2	--	1.96	
91	Pa	233	*	3/2	--	3.4	-3.0
92	U	233	*	5/2	--	0.54	3.5
92	U	235	*	7/2	0.72	0.35	4.1
93	Np	237	*	5/2	--	(6)	
94	Pu	239	*	1/2	--	0.200	--
94	Pu	241	*	5/2	--	-0.686	
95	Am	241	*	5/2	--	1.58	4.9
95	Am	242	*	1	--	0.381	-2.8
95	Am	243	*	5/2	--	1.57	4.9

Table of isotopes of the elements which are naturally occuring and their magnetic moments
Kenneth Lee and Weston A. Anderson (1967)
in CRC Handbook of Chemistry and Physics 66th ed. CRC Press

Isotope			radio-active ?		Natural Abundance	Magnetic Moment μ	Electric Quadrupole Moment Q
Z	El	A		Spin I	%	(eh/4πMc)	(10^{-24} cm^2)
1	H	1		1/2	99.985	2.79268	--
1	H	2		1	1.5×10^{-2}	0.857387	2.73×10^{-3}
2	He	3		1/2	1.3×10^{-4}	-2.1274	--
2	He	4		0	99.99986		
3	Li	6		1	7.42	0.82192	6.9×10^{-4}
3	Li	7		3/2	92.58	3.2560	-3×10^{-2}
4	Be	9		3/2	100	-1.1774	5.2×10^{-2}
5	B	10		3	19.58	1.8007	7.4×10^{-2}
5	B	11		3/2	80.42	2.6880	3.55×10^{-2}
6	C	12		0	98.90		
6	C	13		1/2	1.108	0.702199	--
7	N	14		1	99.63	0.40347	1.6×10^{-2}
7	N	15		1/2	0.37	-0.28298	--
8	O	16		0	99.762		
8	O	17		5/2	3.7×10^{-2}	-1.8930	-2.6×10^{-2}
8	O	18		0	0.2		
9	F	19		1/2	100	2.62727	--
10	Ne	20		0	90.51		
10	Ne	21		3/2	0.257	-0.66140	
10	Ne	22		0	9.22		
12	Mg	24		0	78.99		
12	Mg	25		5/2	10.13	-0.85449	
12	Mg	26		0	11.01		
13	Al	27		5/2	100	3.6385	0.149
14	Si	28		0	92.23		
14	Si	29		1/2	4.70	-0.55477	--
14	Si	30		0	3.10		
15	P	31		1/2	100	1.1305	--
16	S	32		0	95.02		
16	S	33		3/2	0.76	0.64257	-6.4×10^{-2}
16	S	34		0	4.21		
16	S	36		0	0.02		
17	Cl	35		3/2	75.53	0.82091	-7.89×10^{-2}
17	Cl	37		3/2	24.47	0.6833	-6.21×10^{-2}
18	Ar	36		0	0.337		
18	Ar	38		0	0.63		
18	Ar	40		0	99.60		
19	K	39		3/2	93.10	0.39097	0.11
19	K	40	*	4	1.18×10^{-2}	-1.296	
19	K	41		3/2	6.88	0.21459	
20	Ca	40		0	96.914		
20	Ca	42		0	0.647		
20	Ca	43		7/2	0.145	-1.3153	
20	Ca	44		0	2.086		
20	Ca	46		0	0.004		

20	Ca	48	0	0.187		
21	Sc	45	7/2	100	4.7492	-0.22
22	Ti	46	0	8.0		
22	Ti	47	5/2	7.28	-0.78710	
22	Ti	48	0	73.8		
22	Ti	49	7/2	5.51	-1.1022	
22	Ti	50	0	5.4		
23	V	50	6	0.24	3.3413	
23	V	51	7/2	99.76	5.139	-4×10^{-2}
24	Cr	50	0	4.35		
24	Cr	52	0	83.79		
24	Cr	53	3/2	9.55	-0.47354	
24	Cr	54	0	2.36		
25	Mn	55	5/2	100	3.444	0.55
26	Fe	54	0	5.8		
	Fe	56	0	91.72		
	Fe	57	1/2	2.19	0.09024	--
26	Fe	58	0	0.28		
27	Co	59	7/2	100	4.6163	0.40
28	Ni	58	0	68.27		
28	Ni	60	0	26.10		
28	Ni	61	3/2	1.19	-0.74868	
28	Ni	62	0	3.59		
28	Ni	64	0	0.91		
29	Cu	63	3/2	69.09	2.2206	-0.16
29	Cu	65	3/2	30.91	2.3789	-0.15
30	Zn	64	0	48.6		
30	Zn	66	0	27.9		
30	Zn	67	5/2	4.11	0.8733	0.15
30	Zn	68	0	18.8		
30	Zn	70	0	0.6		
31	Ga	69	3/2	60.4	2.011	0.178
31	Ga	71	3/2	39.6	2.5549	0.112
32	Ge	70	0	20.5		
32	Ge	72	0	27.4		
32	Ge	73	9/2	7.76	-0.87679	-0.2
32	Ge	74	0	36.5		
32	Ge	76	0	7.8		
33	As	75	3/2	100	1.4349	0.3
34	Se	74	0	0.9		
34	Se	76	0	9.0		
34	Se	77	1/2	7.58	0.5325	--
34	Se	78	0	23.5		
34	Se	80	0	49.6		
34	Se	82	0	9.4		
35	Br	79	3/2	50.54	2.0990	0.33
35	Br	81	3/2	49.46	2.2626	0.28
36	Kr	78	0	0.35		
36	Kr	80	0	2.25		
36	Kr	82	0	11.6		
36	Kr	83	9/2	11.55	-0.9671	0.15
36	Kr	84	0	57.0		
36	Kr	86	0	17.3		
37	Rb	85	5/2	72.15	1.3482	0.27

37	Rb	87		3/2	27.85	2.7414	0.13
38	Sr	84		0	0.56		
38	Sr	86		0	9.86		
38	Sr	87		9/2	7.02	-1.0893	0.2
38	Sr	88		0	82.58		
39	Y	89		1/2	100	-0.13682	--
40	Zr	90		0	51.45		
40	Zr	91		5/2	11.23	-1.30284	
40	Zr	92		0	17.17		
40	Zr	94		0	17.33		
40	Zr	96		0	2.78		
41	Nb	93		9/2	100	6.1435	-0.2
42	Mo	92		0	14.84		
42	Mo	94		0	9.25		
42	Mo	95		5/2	15.72	0.9097	0.12
42	Mo	96		0	15.92		
42	Mo	97		5/2	9.46	-0.9289	1.1
42	Mo	98		0	16.68		
42	Mo	100		0	24.13		
44	Ru	96		0	5.52		
44	Ru	98		0	1.88		
44	Ru	99		5/2	12.72	-0.6430	
44	Ru	100		0	12.6		
44	Ru	101		5/2	17.07	-0.7207	
44	Ru	102		0	31.6		
44	Ru	104		0	18.7		
45	Rh	103		1/2	100	-0.08790	--
46	Pd	102		0	1.02		
46	Pd	104		0	11.14		
46	Pd	105		5/2	22.23	-0.639	
46	Pd	106		0	+27.33		
46	Pd	108		0	26.46		
46	Pd	110		0	11.72		
47	Ag	107		1/2	51.82	-0.11301	
47	Ag	109		1/2	48.18	-0.12992	
48	Cd	106		0	1.25		
48	Cd	108		0	0.89		
48	Cd	110		0	?12.49?		
48	Cd	111		1/2	12.75	--0.5922	--
48	Cd	112		0	24.13		
48	Cd	113		1/2	12.26	-0.6195	--
48	Cd	114		0	28.73		
48	Cd	116		0	7.49		
49	In	113		9/2	4.28	5.4960	1.14
49	In	115	*	9/2	95.72	5.5079	1.16
50	Sn	112		0	1.0		
50	Sn	114		0	0.7		
50	Sn	115		1/2	0.35	-0.91320	--
50	Sn	116		0	14.7		
50	Sn	117		1/2	7.61	-0.99490	--
50	Sn	118		0	24.3		
50	Sn	119		1/2	8.58	-1.0409	--
50	Sn	120		0	32.4		
50	Sn	122		0	4.6		

50	Sn	124		0	5.66		
51	Sb	121		5/2	57.25	3.3415	-0.5
51	Sb	123		7/2	42.75	2.5334	-0.7
52	Te	120		0	0.096		
52	Te	122		0	2.60		
52	Te	123		1/2	0.87	-0.7319	--
52	Te	124		0	4.816		
52	Te	125		1/2	6.99	-0.8824.	--
52	Te	126		0	18.95		
52	Te	128		0	31.69		
52	Te	130		0	33.80		
53	I	127		5/2	100	2.7937	-0.69
54	Xe	124		0	0.10		
54	Xe	126		0	0.09		
54	Xe	128		0	1.91		
54	Xe	129		1/2	26.44	-0.77247	--
54	Xe	130		0	4.1		
54	Xe	131		3/2	21.18	0.68697	-0.12
54	Xe	132		0	26.9		
54	Xe	134		0	10.4		
54	Xe	136		0	8.9		
55	Cs	133		7/2	100	2.56422	$-3x10^{-3}$
56	Ba	130		0	0.106		
56	Ba	132		0	0.101		
56	Ba	134		0	2.417		
56	Ba	135		3/2	6.59	0.83229	0.25
56	Ba	136		0	7.854		
56	Ba	137		3/2	11.32	0.93107	0.2
56	Ba	138		0	71.70		
57	La	138	*	5	0.089	3.6844	2.7
57	La	139		7/2	99.911	2.7615	0.21
58	Ce	136		0	0.19		
58	Ce	138		0	0.25		
58	Ce	140		0	88.48		
58	Ce	142		0	11.08		
59	Pr	141		5/2	100	4.09	$-5.9x10^{-2}$
60	Nd	142		0	27.13		
60	Nd	143		7/2	12.17	-1.063	-0.48
60	Nd	144		0	23.80		
60	Nd	145		7/2	8.30	-0.654	-0.25
60	Nd	146		0	17.19		
60	Nd	148		0	5.76		
60	Nd	150		0	5.64		
62	Sm	144		0	3.1		
62	Sm	147		7/2	14.97	-0.807	-0.208
62	Sm	148		0	11.3		
62	Sm	149		7/2	13.83	-0.643	$6.0x10^{-2}$
62	Sm	150		0	7.4		
62	Sm	152		0	26.7		
62	Sm	154		0	22.7		
63	Eu	151		5/2	47.82	3.4630	1.16
63	Eu	153		5/2	52.18	1.5292	2.9
64	Gd	152		0	0.20		
64	Gd	154		0	2.18		

64	Gd	155		3/2	14.73	-0.32	1.6
64	Gd	156		0	20.47		
64	Gd	157		3/2	15.68	-0.40	2
64	Gd	158		0	24.84		
64	Gd	160		0	21.86		
65	Tb	159		3/2	100	1.90	1.3
66	Dy	156		0	0.06		
66	Dy	158		0	0.10		
66	Dy	160		0	2.34		
66	Dy	161		5/2	18.88	-0.46	1.4
66	Dy	162		0	25.59		
66	Dy	163		5/2	24.97	0.64	1.6
66	Dy	164		0	28.2		
67	Ho	165		7/2	100	4.01	2.82
68	Er	162		0	0.14		
68	Er	164		0	1.61		
68	Er	166		0	33.6		
68	Er	167		7/2	22.94	-0.565	2.83
68	Er	168		0	26.8		
68	Er	170		0	14.9		
69	Tm	169		1/2	100	-0.231	--
70	Yb	168		0	0.13		
70	Yb	170		0	3.05		
70	Yb	171		1/2	14.31	0.49188	--
70	Yb	172		0	21.9		
70	Yb	173		5/2	16.13	-0.67755	2.8
70	Yb	174		0	31.8		
70	Yb	176		0	12.7		
71	Lu	175		7/2	97.41	2.23	5.68
71	Lu	176	*	7	2.59	3.1	8.0
72	Hf	174		0	0.16		
72	Hf	176		0	5.2		
72	Hf	177		7/2	18.50	0.61	3
72	Hf	178		0	27.1		
72	Hf	179		9/2	13.75	0.47	3
72	Hf	180		0	35.2		
73	Ta	181		7/2	99.988	2.340	3
74	W	180		0	0.13		
74	W	182		0	26.3		
74	W	183		1/2	14.40	0.116205	--
74	W	184		0	30.67		
74	W	186		0	28.6		
75	Re	185		5/2	37.07	3.1437	2.8
75	Re	187	*	5/2	62.93	3.1759	2.6
76	Os	184		0	0.02		
76	Os	186		0	1.58		
76	Os	187		1/2	1.64	0.06432	--
76	Os	188		0	13.3		
76	Os	189		3/2	16.1	0.65004	0.8
76	Os	190		0	26.4		
76	Os	192		0	41.0		
77	Ir	191		3/2	37.3	0.1440	1.5
77	Ir	193		3/2	62.7	0.1568	1.5
78	Pt	190		0	0.01		

78	Pt	192		0	0.79		
78	Pt	194		0	32.9		
78	Pt	195		1/2	33.8	0.6004	--
78	Pt	196		0	25.3		
78	Pt	198		0	7.2		
79	Au	197		3/2	100	0.143489	0.59
80	Hg	196		0	0.15		
80	Hg	198		0	10.1		
80	Hg	199		1/2	16.84	0.497859	
80	Hg	200		0	23.1		
80	Hg	201		3/2	13.22	-0.55293	0.50
80	Hg	202		0	29.65		
80	Hg	204		0	6.8		
81	Tl	2O3		1/2	29.50	1.5960	--
81	Tl	205		1/2	70.50	1.6116	--
82	Pb	204		0	1.4		
82	Pb	206		0	24.1		
82	Pb	207		1/2	22.6	0.584284	--
82	Pb	208		0	52.4		
83	Bi	209	*	9/2	100	4.03896	-0.4
90	Th	232		0	100		
92	U	235	*	7/2	0.72	0.35	4.1

Appendix G

Table of naturally occuring isotopes of the elements with nuclear spin of zero and their magnetic moments
Kenneth Lee and Weston A. Anderson (1967)
in CRC Handbook of Chemistry and Physics, 66th ed. CRC Press

Isotope			radio-active ?		Natural Abundance	Magnetic Moment μ	Electric Quadrupole Moment Q
Z	El	A		Spin I	%	(eh/4πMc)	(10^{-24} cm^2)
0	n	1	*	1/2	--	-1.91315	--
1	H	1		1/2	99.985	2.79268	--
1	H	2		1	$1.5x10^{-2}$	0.857387	$2.73x10^{-3}$
1	H	3	*	1/2	--	2.97877	--
2	He	3		1/2	$1.3x10^{-4}$	-2.1274	--
3	Li	6		1	7.42	0.82192	$6.9x10^{-4}$
3	Li	7		3/2	92.58	3.2560	$-3x10^{-2}$
3	Li	8	*	2	--	1.653	
4	Be	9		3/2	100	-1.1774	$5.2x10^{-2}$
5	B	10		3	19.58	1.8007	$7.4x10^{-2}$
5	B	11		3/2	80.42	2.6880	$3.55x10^{-2}$
6	C	13		1/2	1.108	0.702199	--
7	N	13	*	1/2	--	(-)0.322	--
7	N	14		1	99.63	0.40347	$1.6x10^{-2}$
7	N	15		1/2	0.37	-0.28298	--
8	O	15	*	1/2	--	0.719	--
8	O	17		5/2	$3.7x10^{-2}$	-1.8930	$-2.6x10^{-2}$
9	F	17	*	5/2	--	4.720	
9	F	19		1/2	100	2.62727	--
9	F	20	*	2	--	2.093	
10	Ne	19	*	(1/2)	--	-1.886	
10	Ne	21		3/2	0.257	-0.66140	
11	Na	21	*	3/2	--	2.3861	
11	Na	22	*	3	--	1.746	
11	Na	23		3/2	100	2.2161	0.14-0.15
11	Na	24	*	4	--	1.690	
12	Mg	25		5/2	10.13	-0.85449	
13	Al	27		5/2	100	3.6385	0.149
14	Si	29		1/2	4.70	-0.55477	--
15	P	31		1/2	100	1.1305	--
15	P	32	*	1	--	-0.2523	
16	S	33		3/2	0.76	0.64257	$-6.4x10^{-2}$
16	S	35	*	3/2	--	1.00	$4.54x10^{-2}$
17	Cl	35		3/2	75.53	0.82091	$-7.89x10^{-2}$
17	Cl	36	*	2	--	1.2838	$-1.72x10^{-2}$
17	Cl	37		3/2	24.47	0.6833	$-6.21x10^{-2}$
18	Ar	37	*	3/2	--	1.0	
19	K	38	*	3	--	1.374	
19	K	39		3/2	93.10	0.39097	0.11
19	K	40	*	4	$1.18x10^{-2}$	-1.296	
19	K	41		3/2	6.88	0.21459	
19	K	42	*	2	--	-1.140	
19	K	43	*	3/2	--	0.163	
20	Ca	41	*	7/2	--	-1.5924	

20	Ca	43		7/2	0.145	-1.3153	
21	Sc	43	*	7/2	--	4.61	-0.26
21	Sc	44	*	2	--	2.56	0.14
21	Sc	44	*	6	--	3.96	0.37
21	Sc	45		7/2	100	4.7492	-0.22
21	Sc	46	*	4	--	3.03	0.12
21	Sc	47	*	7/2	--	5.33	-0.22
22	Ti	45	*	7/2	--	0.095	$1.5x10^{-2}$
22	Ti	47		5/2	7.28	-0.78710	
22	Ti	49		7/2	5.51	-1.1022	
23	V	49	*	7/2	--	4.46	
23	V	50		6	0.24	3.3413	
23	V	51		7/2	99.76	5.139	$-4x10^{-2}$
24	Cr	53		3/2	9.55	-0.47354	
25	Mn	52	*	6	--	3.075	
2	Mn	52	*	2	--	0.008	
2	Mn	53	*	7/2	--	5.05	
25	Mn	54	*	(2)(3)	--	(2.2)(2.6)	
25	Mn	55		5/2	100	3.444	0.55
25	Mn	56	*	3	--	3.240	
26	Fe	57		1/2	2.19	0.09024	--
27	Co	55	*	7/2	--	4.6	
27	Co	56	*	4	--	3.85	
27	Co	57	*	7/2	--	4.65	
27	Co	58	*	2	--	4.05	
27	Co	59		7/2	100	4.6163	0.40
27	Co	60	*	5	--	3.800	
28	Ni	61		3/2	1.19	-0.74868	
29	Cu	61	*	3/2	--	2.13	
29	Cu	63		3/2	69.09	2.2206	-0.16
29	Cu	64	*	1	--	0.40	
29	Cu	65		3/2	30.91	2.3789	-0.15
29	Cu	66	*	1	--	-0.216	
30	Zn	65	*	5/2	--	0.7692	$-2.4x10^{-2}$
30	Zn	67		5/2	4.11	0.8733	0.15
31	Ga	68	*	1	--	0.0117	$3.1x10^{-2}$
31	Ga	69		3/2	60.4	2.011	0.178
31	Ga	71		3/2	39.6	2.5549	0.112
31	Ga	72	*	3	--	-0.13220	0.72
32	Ge	71	*	1/2	--	0.55	--
32	Ge	73		9/2	7.76	-0.87679	-0.2
33	As	75		3/2	100	1.4349	0.3
33	As	76	*	2	--	-0.906	
34	Se	77		1/2	7.58	0.5325	--
34	Se	79		7/2	--	-1.02	0.9
35	Br	76	*	1	--	(-)0.548	0.27
35	Br	79		3/2	50.54	2.0990	0.33
35	Br	80	*	1	--	0.514	0.20
35	Br	80m	*	5	--	1.317	0.76
35	Br	81		3/2	49.46	2.2626	0.28
35	Br	82	*	5	--	(+)1.626	(+)0.76
36	Kr	83		9/2	11.55	-0.9671	0.15
36	Kr	85	*	9/2	--	-1.001	0.25
37	Rb	81	*	3/2	--	2.05	

37	Rb	82m	*	5	--	1.50	
37	Rb	83	*	5/2	--	1.42	
37	Rb	84	*	2	--	-1.32	
37	Rb	85		5/2	72.15	1.3482	0.27
37	Rb	86	*	2	--	-1.69	
37	Rb	87		3/2	27.85	2.7414	0.13
38	Sr	87		9/2	7.02	-1.0893	0.2
39	Y	89		1/2	100	-0.13682	--
39	Y	90	*	2	--	-1.62	-0.16
39	Y	91	*	1/2	--	0.163	--
40	Zr	91		5/2	11.23	-1.30284	
41	Nb	93		9/2	100	6.1435	-0.2
42	Mo	95		5/2	15.72	0.9097	0.12
42	Mo	97		5/2	9.46	-0.9289	1.1
43	Tc	99	*	9/2	--	5.6572	0.3
44	Ru	99		5/2	12.72	-0.6430	
44	Ru	101		5/2	17.07	-0.7207	
45	Rh	103		1/2	100	-0.08790	--
46	Pd	105		5/2	22.23	-0.639	
47	Ag	104	*	5	--	4.0	
47	Ag	104m	*	2	--	3.7	
47	Ag	105	*	1/2	--	0.101	--
47	Ag	107		1/2	51.82	-0.11301	
47	Ag	108	*	1	--	4.2	
47	Ag	109		1/2	48.18	-0.12992	
47	Ag	110m	*	6	--	3.587	
47	Ag	111	*	1/2	--	-0.145	
47	Ag	112	*	2	--	0.0545	
47	Ag	113	*	1/2	--	0.158	
48	Cd	107	*	5/2	--	-0.6162	0.8
48	Cd	109	*	5/2	--	-0.8293	0.8
48	Cd	111		1/2	12.75	--0.5922	--
48	Cd	113		1/2	12.26	-0.6195	--
48	Cd	113m	*	11/2	--	-1.09	-0.79
48	Cd	115	*	1/2	--	-0.649	--
48	Cd	115m	*	11/2	--	-1.044	-0.61
49	In	113		9/2	4.28	5.4960	1.14
49	In	113m	*	1/2	--	-0.2105	--
49	In	114m	*	5	--	4.7	
49	In	115	*	9/2	95.72	5.5079	1.16
49	In	115m	*	1/2	--	-0.2437	--
49	In	116	*	5	--	4.21	
49	In	116m	*	5	--	4.4	
50	Sn	115		1/2	0.35	-0.91320	--
50	Sn	117		1/2	7.61	-0.99490	--
50	Sn	119		1/2	8.58	-1.0409	--
51	Sb	121		5/2	57.25	3.3415	-0.5
51	Sb	122	*	2	--	-1.90	
51	Sb	123		7/2	42.75	2.5334	-0.7
52	Te	119	*	1/2	--	0.27	--
52	Te	123		1/2	0.87	-0.7319	--
52	Te	125		1/2	6.99	-0.8824.	--
53	I	125	*	5/2	--	3	-0.66
53	I	127		5/2	100	2.7937	-0.69

53	I	129	*	7/2	--	2.6031	-0.48
53	I	131	*	7/2	--	2.738	-0.41
54	Xe	129		1/2	26.44	-0.77247	--
54	Xe	131		3/2	21.18	0.68697	-0.12
55	Cs	127	*	1/2	--	1.4.3	--
55	Cs	129	*	1/2	--	1.47	--
55	Cs	130	*	1	--	1.4	
55	Cs	131	*	5/2	--	3.517	
55	Cs	132	*	2	--	2.22	
55	Cs	133		7/2	100	2.56422	-3×10^{-3}
55	Cs	134	*	4	--	2.973	0.43
55	Cs	134m	*	8	--	1.0964	
55	Cs	135	*	7/2	--	2.7134	
55	Cs	137	*	7/2	--	2.8219	
56	Ba	135		3/2	6.59	0.83229	0.25
56	Ba	137		3/2	11.32	0.93107	0.2
57	La	138	*	5	0.089	3.6844	2.7
57	La	139		7/2	99.911	2.7615	0.21
58	Ce	137	*	3/2	--	0.9	
58	Ce	137m	*	11/2	--	0.69	
58	Ce	139	*	3/2	--	1.0	
58	Ce	141	*	7/2	--	0.97	
58	Ce	143	*	7/2	--	1.0	
59	Pr	141		5/2	100	4.09	-5.9×10^{-2}
59	Pr	142	*	2	--	0.30	4×10^{-2}
60	Nd	143		7/2	12.17	-1.063	-0.48
60	Nd	145		7/2	8.30	-0.654	-0.25
60	Nd	147	*	5/2	--	0.579	
61	Pm	143	*	(5/2)(7/2)	--	(3.8)(3.9)	
61	Pm	144	*	(5)(6)	--	(1.7)(1.8)	
61	Pm	147	*	7/2	--	2.58	0.7
61	Pm	148	*	1	--	2.1	0.2
61	Pm	148m	*	6	--	1.8	
61	Pm	149	*	7/2	--	3.3	
61	Pm	151	*	5/2	--	1.8	1.9
62	Sm	147		7/2	14.97	-0.807	-0.208
62	Sm	149		7/2	13.83	-0.643	6.0×10^{-2}
63	Eu	151		5/2	47.82	3.4630	1.16
63	Eu	152	*	3	--	1.912	
63	Eu	153		5/2	52.18	1.5292	2.9
63	Eu	154	*	3	--	2.001	
64	Gd	155		3/2	14.73	-0.32	1.6
64	Gd	157		3/2	15.68	-0.40	2
65	Tb	156	*	3	--	1.5	1.4
65	Tb	159		3/2	100	1.90	1.3
65	Tb	160	*	3	--	1.6	1.9
66	Dy	155	*	(3/2)	--	0.21	
66	Dy	157	*	(3/2)	--	0 32	
66	Dy	161		5/2	18.88	-0.46	1.4
66	Dy	163		5/2	24.97	0.64	1.6
67	Ho	165		7/2	100	4.01	2.82
68	Er	165	*	5/2	--	0.65	2.2
68	Er	167		7/2	22.94	-0.565	2.83
68	Er	169	*	1/2	--	0.51	--

68	Er	171	*	5/2	--	0.70	
69	Tm	166	*	2	--	0.05	4.6
69	Tm	169		1/2	100	-0.231	--
69	Tm	170	*	1	--	0.26	0.61
69	Tm	171	*	1/2	--	0.227	--
70	Yb	171		1/2	14.31	0.49188	--
70	Yb	173		5/2	16.13	-0.67755	2.8
70	Yb	175	*	(7/2)	--	-0.15	
71	Lu	175		7/2	97.41	2.23	5.68
71	Lu	176	*	7	2.59	3.1	8.0
71	Lu	177	*	7/2	--	2.22	5.51
72	Hf	177		7/2	18.50	0.61	3
72	Hf	179		9/2	13.75	0.47	3
73	Ta	181		7/2	99.988	2.340	3
74	W	183		1/2	14.40	0.116205	--
75	Re	185		5/2	37.07	3.1437	2.8
75	Re	186	*	1	--	1.728	
75	Re	187	*	5/2	62.93	3.1759	2.6
75	Re	188	*	1	--	1.777	
76	Os	187		1/2	1.64	0.06432	--
76	Os	189		3/2	16.1	0.65004	0.8
77	Ir	191		3/2	37.3	0.1440	1.5
77	Ir	193		3/2	62.7	0.1568	1.5
78	Pt	195		1/2	33.8	0.6004	--
79	Au	190	*	1	--	0.065	
79	Au	194	*	1	--	0.073	
79	Au	195	*	3/2	--	0.146	
79	Au	196	*	2	--	0.6	
79	Au	197		3/2	100	0.143489	0.59
79	Au	198	*	2	--	0.5842	
79	Au	199	*	3/2	--	0.2673	
80	Hg	193	*	3/2	--	-0.61	
80	Hg	193m	*	13/2	--	-1.05	1.37
80	Hg	195	*	1/2	--	0.53	--
80	Hg	195m	*	13/2	--	-1.04	1.41
80	Hg	197	*	1/2	--	0.52	--
80	Hg	199		1/2	16.84	0.497859	
80	Hg	201		3/2	13.22	-0.55293	0.50
80	Hg	2O3	*	5/2	--	0.83	0.5
81	Tl	197	*	1/2	--	1.55	--
81	Tl	199	*	1/2	--	1.57	--
81	Tl	200	*	2	--	(0.15)	
81	Tl	201	*	1/2	--	1.58	--
81	Tl	202	*	2	--	(0.15)	
81	Tl	2O3		1/2	29.50	1.5960	--
81	Tl	2O4	*	2	--	0.089	
81	Tl	205		1/2	70.50	1.6116	--
82	Pb	207		1/2	22.6	0.584284	--
83	Bi	203	*	9/2	--	4.59	-0.64
83	Bi	204	*	6	--	4.25	-0.41
83	Bi	205	*	9/2	--	(5.5)	
83	Bi	206	*	6	--	4.56	-0.19
83	Bi	209	*	9/2	100	4.03896	-0.4
83	Bi	210	*	1	--	0.0442	0.13

84	Po	205	*	5/2	--	0.26	0.17
84	Po	207	*	5/2	--	0.27	0.28
89	Ac	227	*	3/2	--	1.1	-1.7
90	Th	229	*	5/2	--	0.4	4.6
91	Pa	231	*	3/2	--	1.96	
91	Pa	233	*	3/2	--	3.4	-3.0
92	U	233	*	5/2	--	0.54	3.5
92	U	235	*	7/2	0.72	0.35	4.1
93	Np	237	*	5/2	--	(6)	
94	Pu	239	*	1/2	--	0.200	--
94	Pu	241	*	5/2	--	-0.686	
95	Am	241	*	5/2	--	1.58	4.9
95	Am	242	*	1	--	0.381	-2.8
95	Am	243	*	5/2	--	1.57	4.9